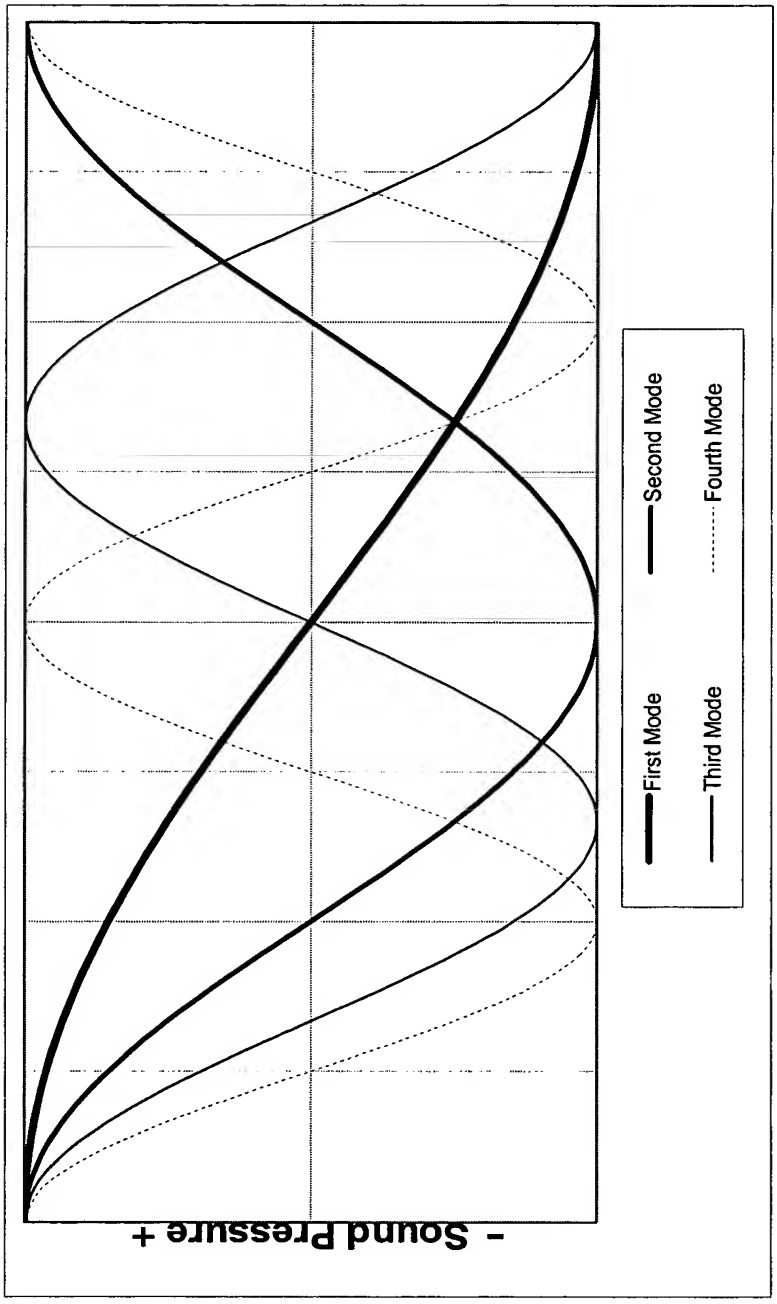
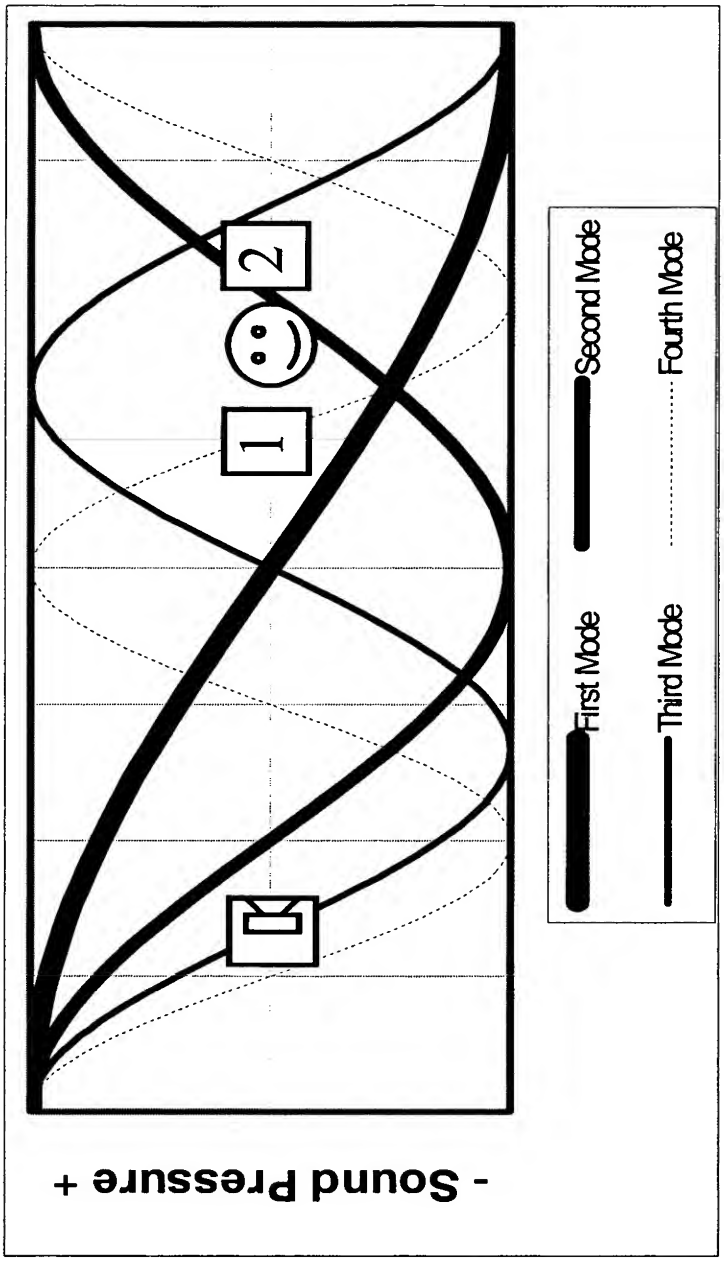
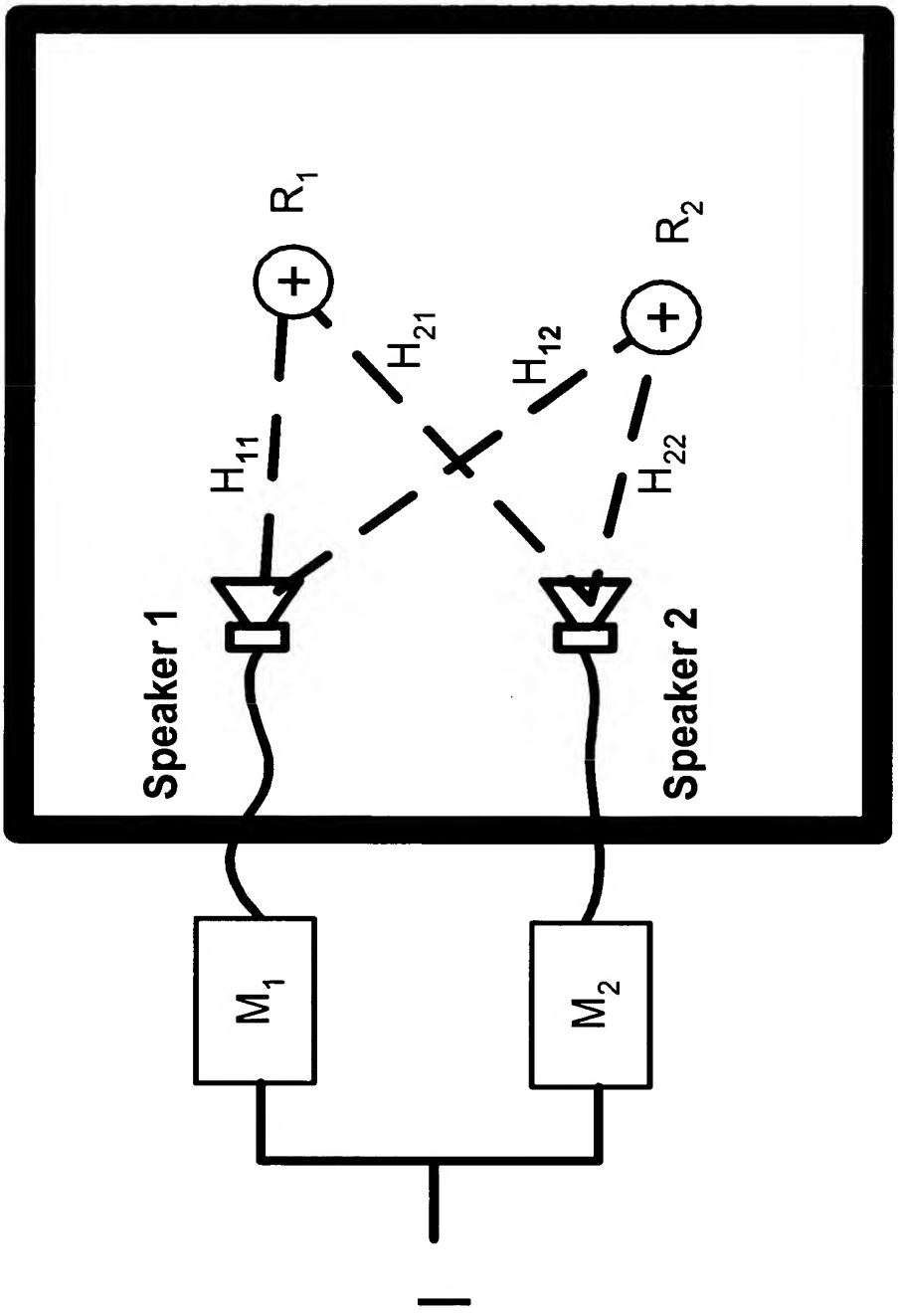

- Sound Pressure +
First Mode
Second Mode
Third Mode
Fourth Mode

FIG. 1



PRIOR ART

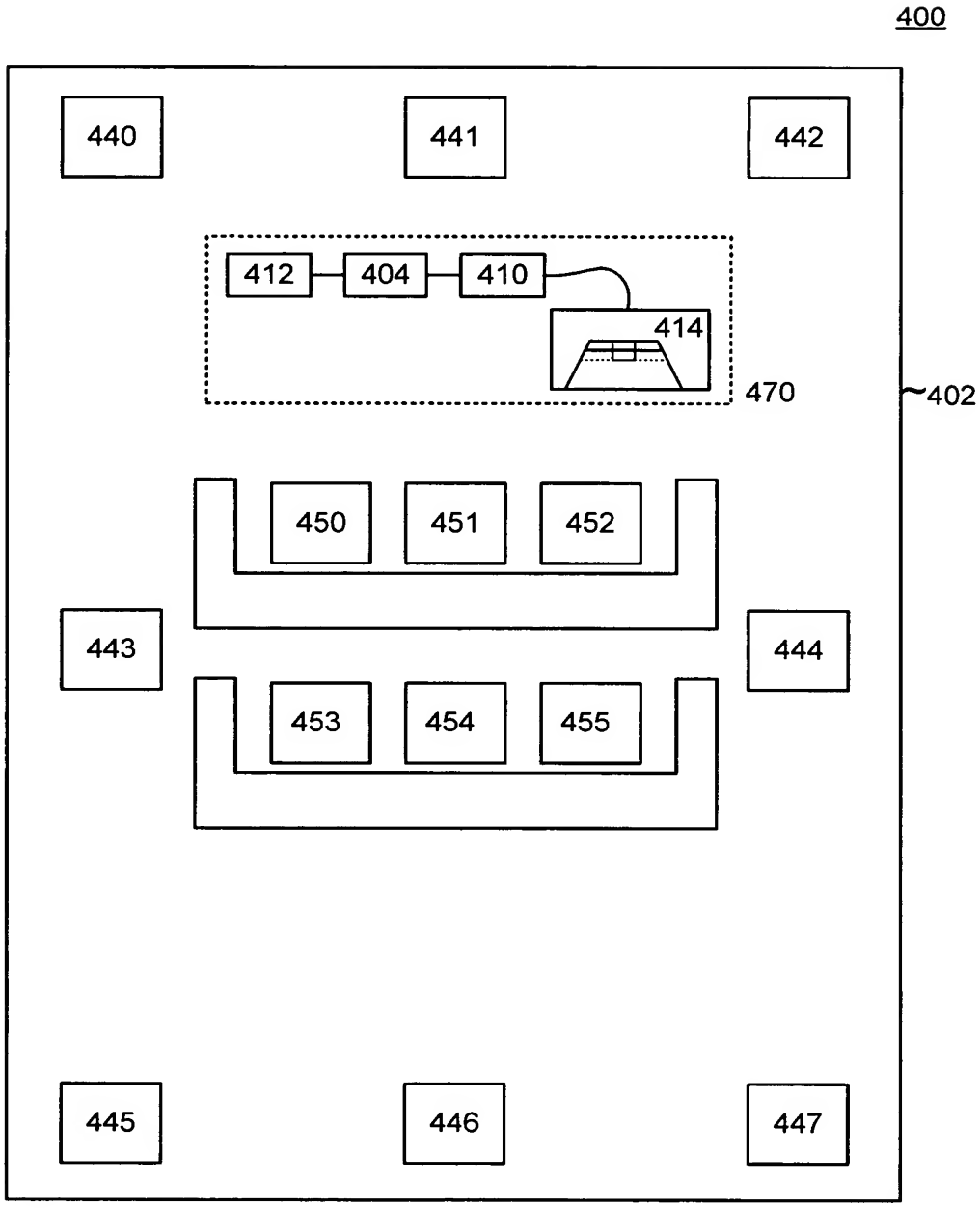
FIG. 2



PRIOR ART

FIG. 3

FIG. 4


400
440
441
442
412
404
410
414
470
402
450
451
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445
446
447

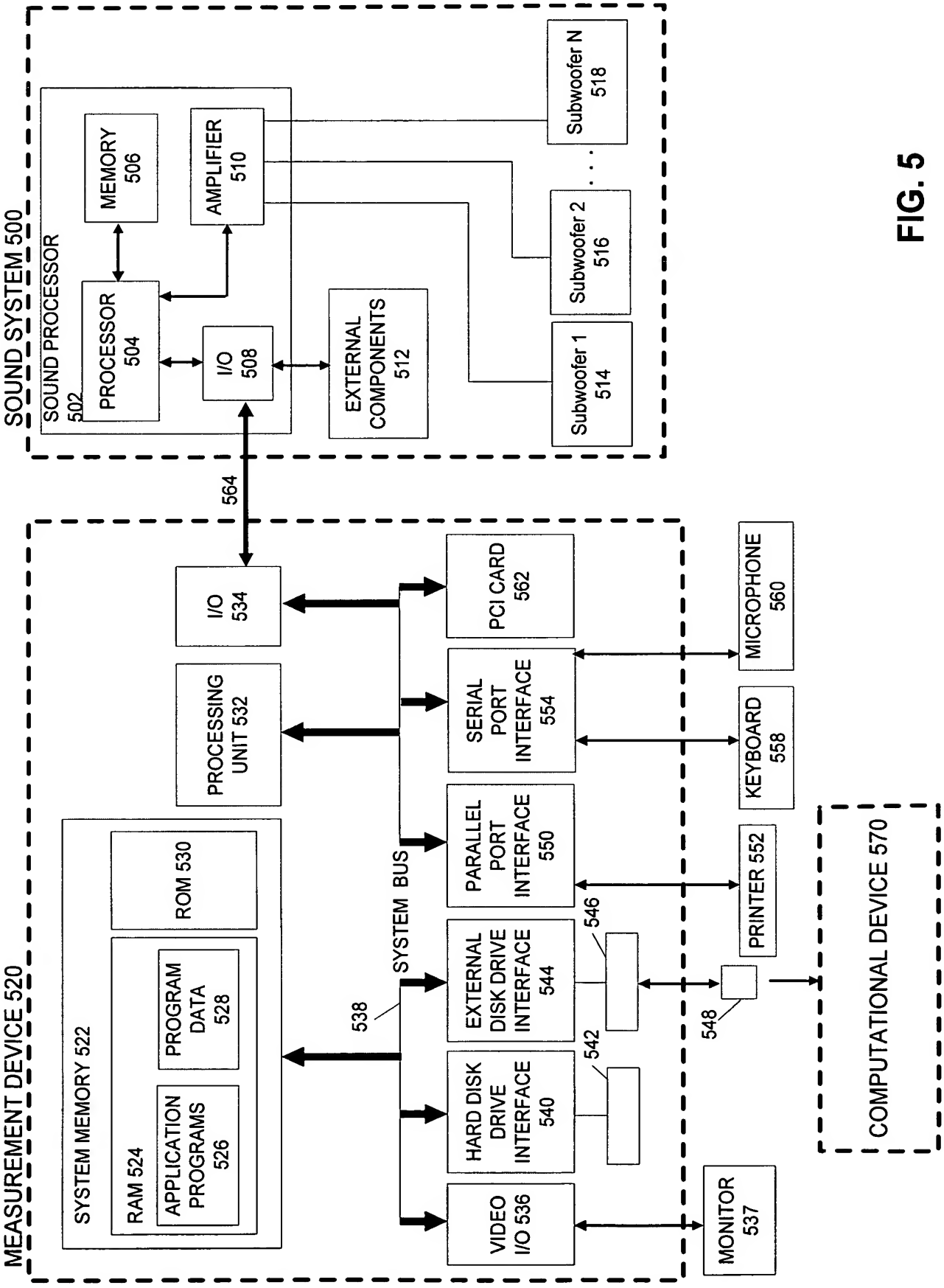

SOUND SYSTEM 500
SOUND PROCESSOR 502
PROCESSOR 504
MEMORY 506
AMPLIFIER 510
I/O 508
EXTERNAL COMPONENTS 512
Subwoofer 1 514
Subwoofer 2 516
Subwoofer N 518
564
MEASUREMENT DEVICE 520
I/O 534
PROCESSING UNIT 532
SYSTEM MEMORY 522
ROM 530
RAM 524
APPLICATION PROGRAMS 526
PROGRAM DATA 528
538
SYSTEM BUS
PCI CARD 562
SERIAL PORT INTERFACE 554
PARALLEL PORT INTERFACE 550
EXTERNAL DISK DRIVE INTERFACE 544
HARD DISK DRIVE INTERFACE 540
VIDEO I/O 536
546
542
548
MICROPHONE 560
KEYBOARD 558
PRINTER 552
COMPUTATIONAL DEVICE 570
MONITOR 537

FIG. 5

FIG. 6

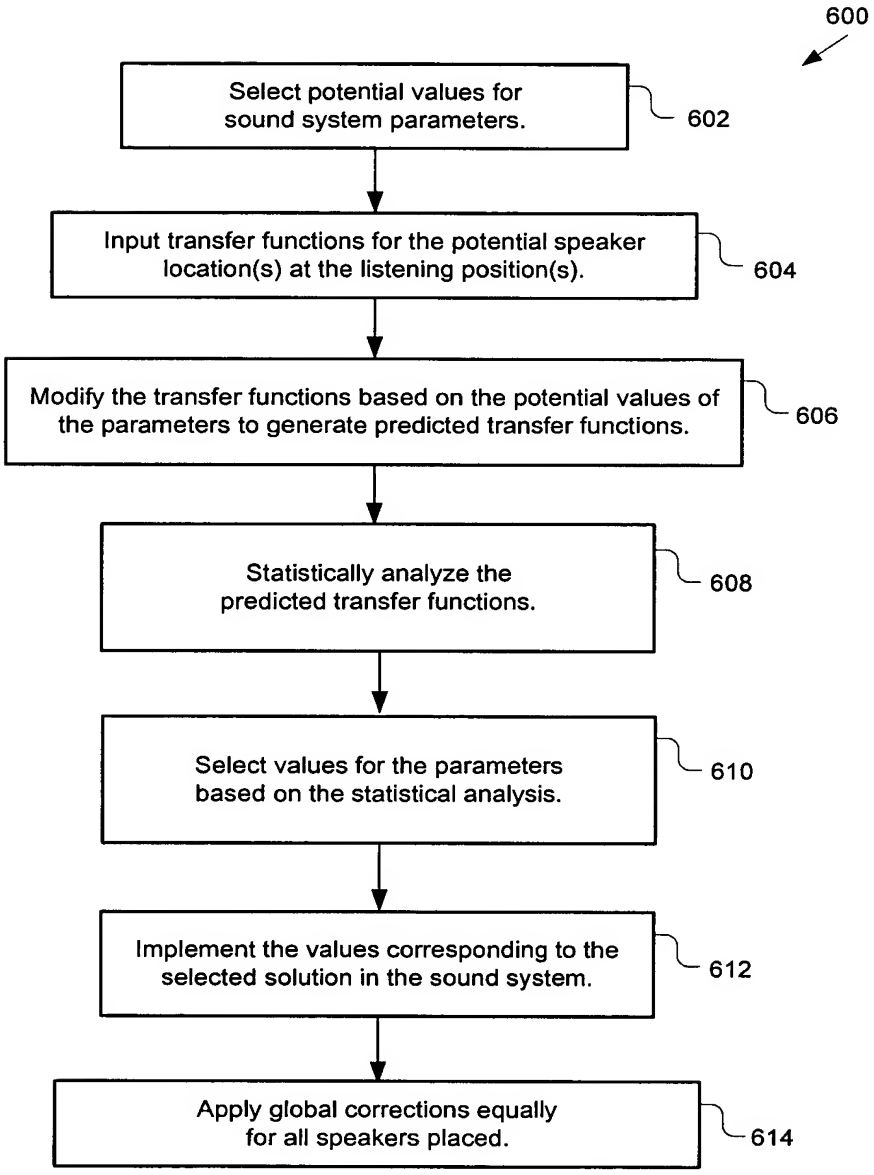

600
Select potential values for sound system parameters.
602
Input transfer functions for the potential speaker location(s) at the listening position(s).
604
Modify the transfer functions based on the potential values of the parameters to generate predicted transfer functions.
606
Statistically analyze the predicted transfer functions.
608
Select values for the parameters based on the statistical analysis.
610
Implement the values corresponding to the selected solution in the sound system.
612
Apply global corrections equally for all speakers placed.
614

FIG. 7

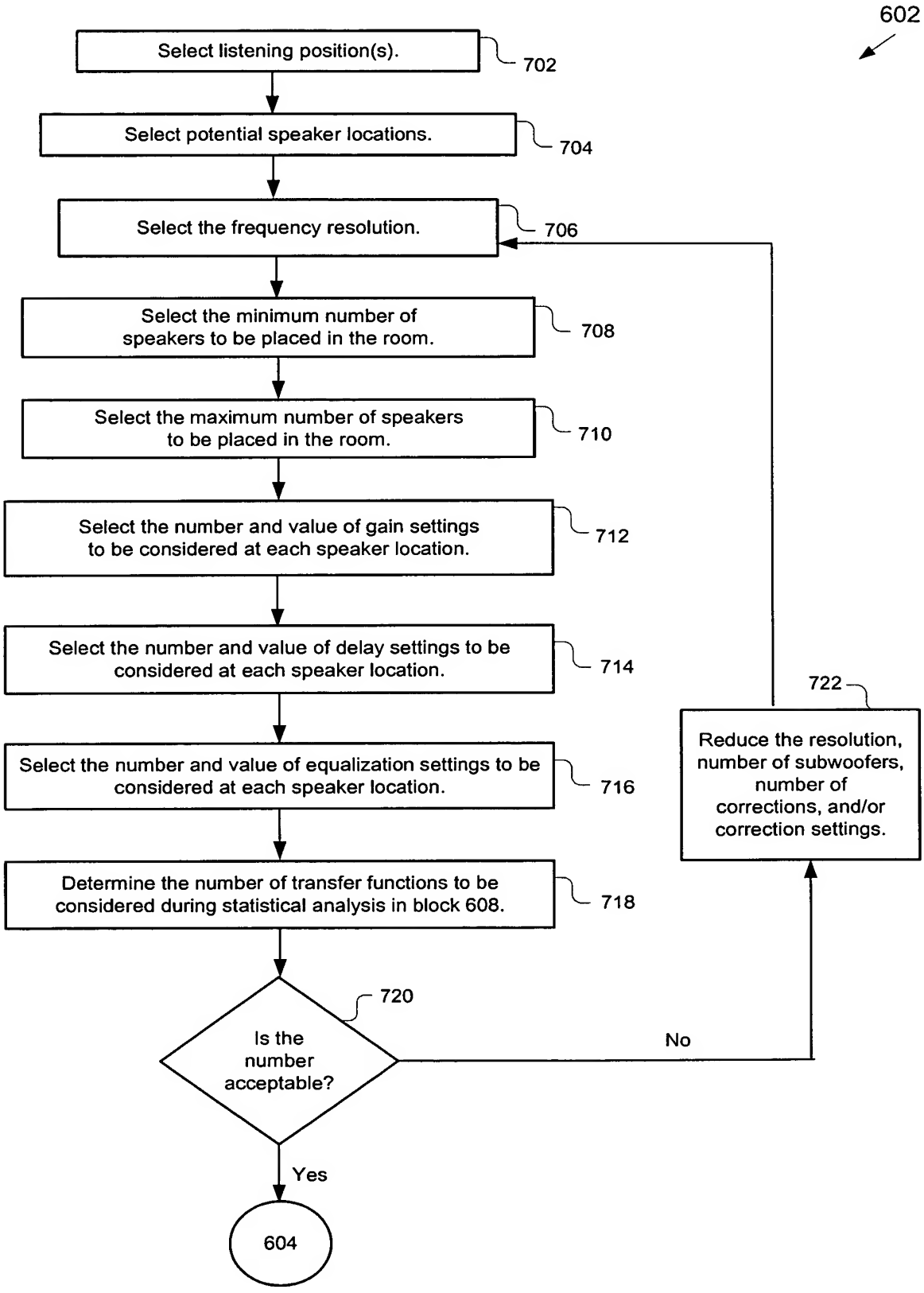

602
Select listening position(s).
702
Select potential speaker locations.
704
Select the frequency resolution.
706
Select the minimum number of speakers to be placed in the room.
708
Select the maximum number of speakers to be placed in the room.
710
Select the number and value of gain settings to be considered at each speaker location.
712
Select the number and value of delay settings to be considered at each speaker location.
714
Select the number and value of equalization settings to be considered at each speaker location.
716
Determine the number of transfer functions to be considered during statistical analysis in block 608.
718
Is the number acceptable?
720
No
Yes
Reduce the resolution, number of subwoofers, number of corrections, and/or correction settings.
722
604

FIG. 8

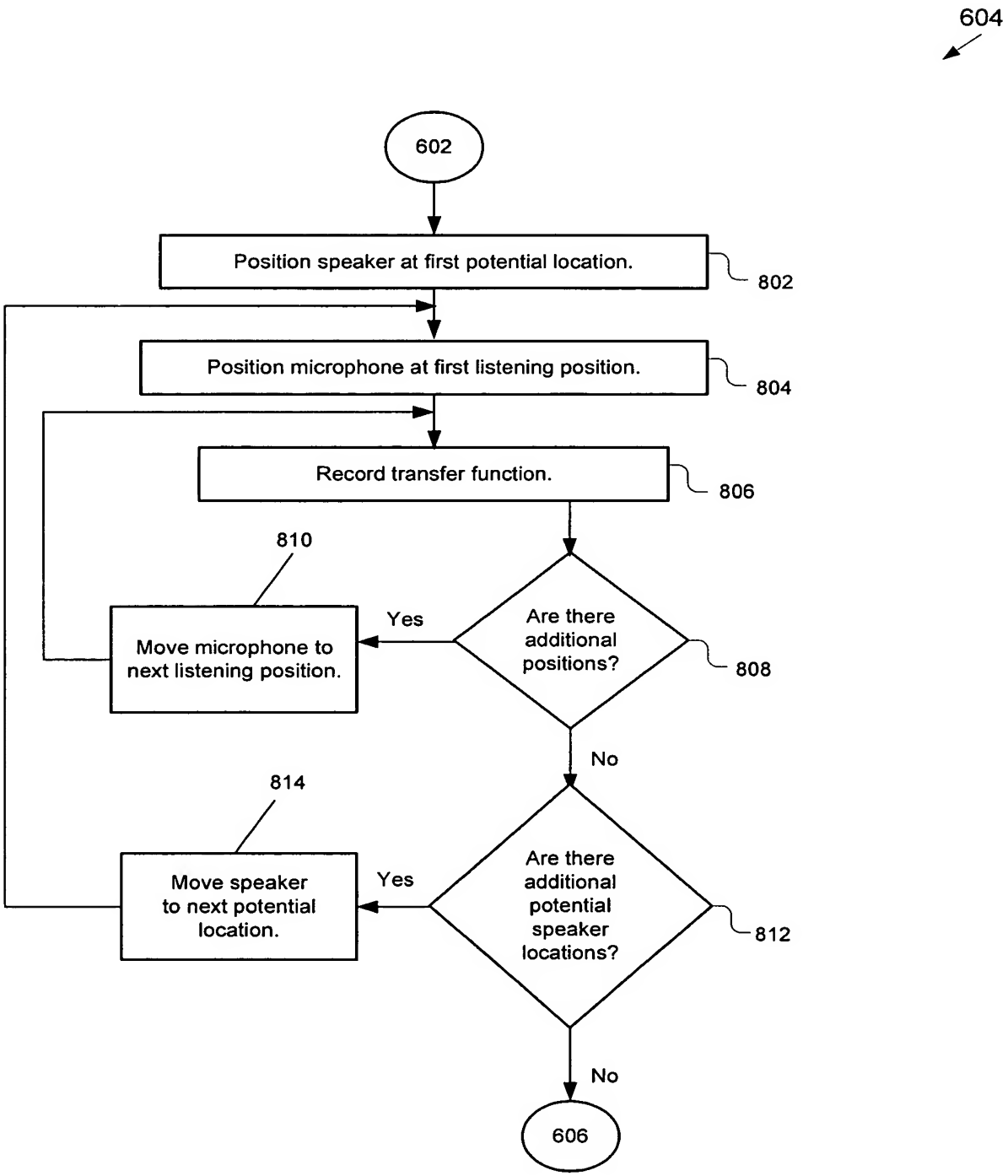
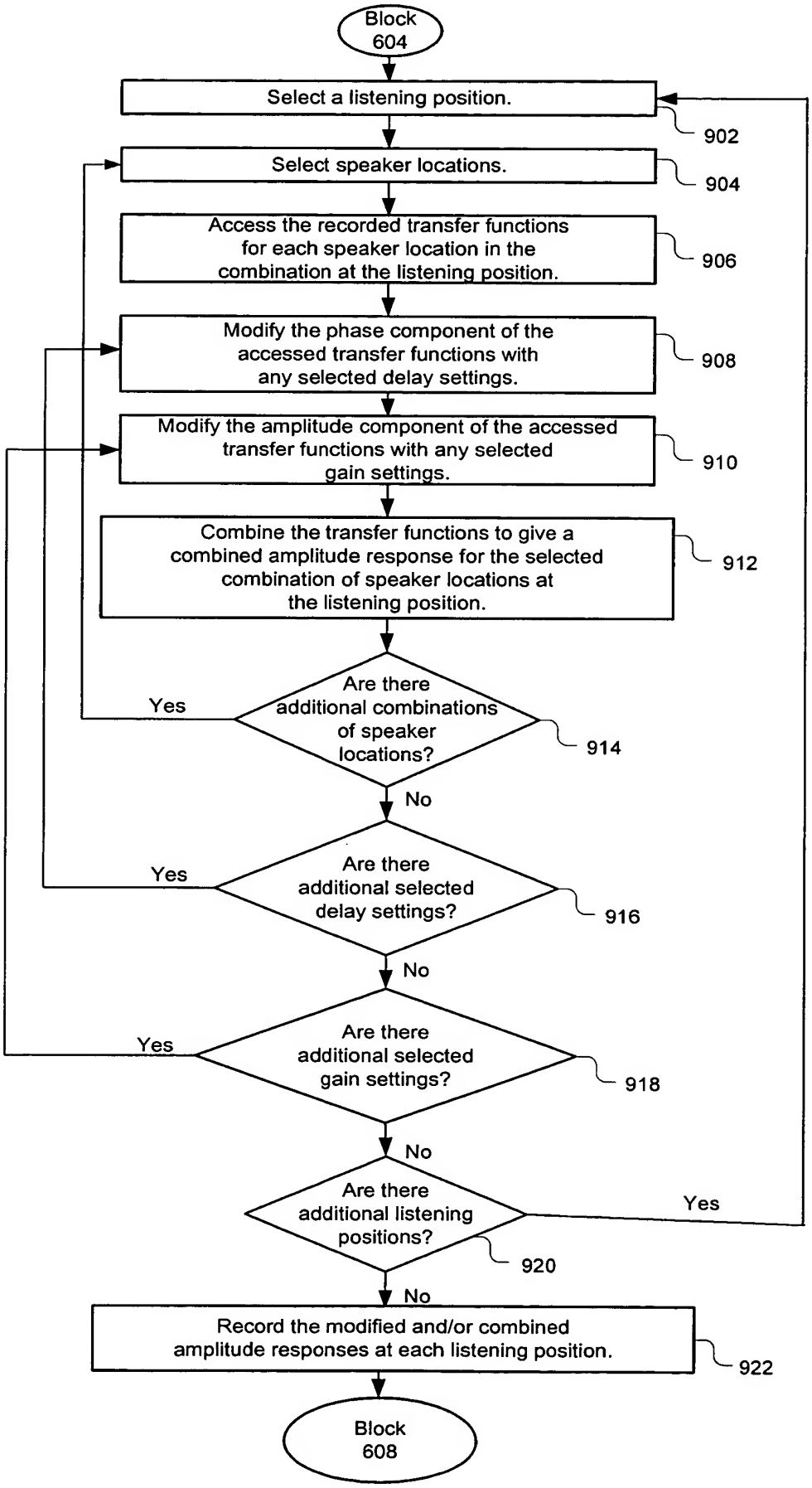

604
602
Position speaker at first potential location.
802
Position microphone at first listening position.
804
Record transfer function.
806
810
Move microphone to next listening position.
Yes
Are there additional positions?
808
No
814
Move speaker to next potential location.
Yes
Are there additional potential speaker locations?
812
No
606

FIG. 9


606
Block 604
Select a listening position.
902
Select speaker locations.
904
Access the recorded transfer functions for each speaker location in the combination at the listening position.
906
Modify the phase component of the accessed transfer functions with any selected delay settings.
908
Modify the amplitude component of the accessed transfer functions with any selected gain settings.
910
Combine the transfer functions to give a combined amplitude response for the selected combination of speaker locations at the listening position.
912
Are there additional combinations of speaker locations?
914
Yes
No
Are there additional selected delay settings?
916
Yes
No
Are there additional selected gain settings?
918
Yes
No
Are there additional listening positions?
920
Yes
No
Record the modified and/or combined amplitude responses at each listening position.
922
Block 608

	Raw Data									
frequency	seat 1	seat 2	seat 3	seat 4	seat 5	Spatial Average	Spatial Variance	Spatial STDEV	Spatial Envelope	Spatial Max-ave
20	-17.71	-16.38	-18.13	-14.51	-12.99	-15.94	4.72	2.17	5.14	2.96
22	-16.60	-15.62	-15.44	-5.07	-6.21	-11.79	31.88	5.65	11.53	6.72
24	-17.26	-24.25	-20.21	-10.22	-13.12	-17.01	31.00	5.57	14.03	6.79
26	-11.73	-14.44	-16.10	-8.19	-9.83	-12.06	10.53	3.25	7.92	3.87
28	-11.72	-14.14	-13.79	-3.30	-8.24	-10.24	20.54	4.53	10.83	6.94
30	-19.70	-17.51	-13.79	-8.16	-8.69	-13.57	26.58	5.16	11.54	5.41
32	-22.44	-22.50	-19.69	-13.33	-12.41	-18.07	23.96	4.90	10.09	5.66
34	-19.80	-19.50	-21.25	-17.85	-16.70	-19.02	3.14	1.77	4.55	2.32
36	-19.06	-19.48	-18.22	-13.00	-19.80	-17.91	7.89	2.81	6.80	4.91
38	-19.83	-17.91	-20.68	-14.88	-23.61	-19.38	10.54	3.25	8.73	4.50
40	-18.75	-16.72	-17.08	-20.89	-22.82	-19.25	6.71	2.59	6.10	2.53
42	-15.02	-13.59	-14.73	-18.38	-21.44	-16.63	10.41	3.23	7.85	3.04
44	-13.85	-12.98	-13.78	-21.20	-18.60	-16.08	13.10	3.62	8.22	3.10
46	-15.85	-13.80	-12.74	-18.62	-13.84	-14.97	5.43	2.33	5.88	2.23
48	-16.58	-12.29	-15.48	-14.20	-10.02	-13.71	6.80	2.61	6.55	3.69
50	-6.76	-4.32	-7.56	-12.47	-6.48	-7.52	9.09	3.02	8.15	3.20
52	0.47	2.07	-0.50	-7.13	-0.89	-1.19	12.33	3.51	9.21	3.27
54	5.22	7.20	5.79	-0.33	5.60	4.70	8.45	2.91	7.53	2.50
56	5.60	7.68	6.99	2.99	8.86	6.42	5.07	2.25	5.87	2.44
58	4.13	5.71	5.20	2.36	8.14	5.11	4.52	2.13	5.78	3.03
60	1.31	2.94	3.23	2.15	6.85	3.30	4.50	2.12	5.54	3.55
62	-0.95	0.43	1.43	-0.04	2.53	0.68	1.80	1.34	3.47	1.85
64	-6.34	-4.22	-2.79	-1.93	0.77	-2.90	7.00	2.64	7.11	3.67
66	-6.57	-3.47	-1.77	-6.68	-4.59	-4.62	4.37	2.09	4.91	2.85
68	-2.12	0.25	1.84	-18.61	-7.12	-5.15	68.03	8.25	20.45	6.99
70	-6.24	-4.01	-0.33	-5.86	-1.09	-3.51	7.29	2.70	5.91	3.17
72	-5.02	-1.94	-3.21	-4.27	-1.03	-3.09	2.68	1.64	3.99	2.06
74	-6.33	-1.93	0.01	-9.78	-10.56	-5.72	21.88	4.68	10.57	5.73
76	-8.14	-3.79	-1.29	-12.48	-18.59	-8.86	47.82	6.92	17.30	7.57
78	-21.63	-9.69	-4.21	-16.46	-8.91	-12.18	47.03	6.86	17.42	7.97
80	-5.65	-10.12	-6.63	-11.59	-5.71	-7.94	7.50	2.74	5.94	2.29
Mean Level	-10.16	-8.66	-8.22	-9.74	-8.08	Mean Overall Level	Mean Spatial Variance	Mean Spatial STDEV	Mean Spatial Envelope	Mean Spatial Max-ave
Mean Overall Level			-8.97			-8.97	15.24	3.52	8.55	4.09
Variance of Mean Levels			0.86							
STDEV of Mean Levels			0.93							
Envelope of Mean Levels			2.08							
Max-ave of Mean Levels			0.89							

Variance of Spatial Average	STDEV of Spatial Average	Envelope of Spatial Average	Max-ave of Spatial Average
62.7919	7.924135	25.80	15.39

FIG. 10

FIG. 11

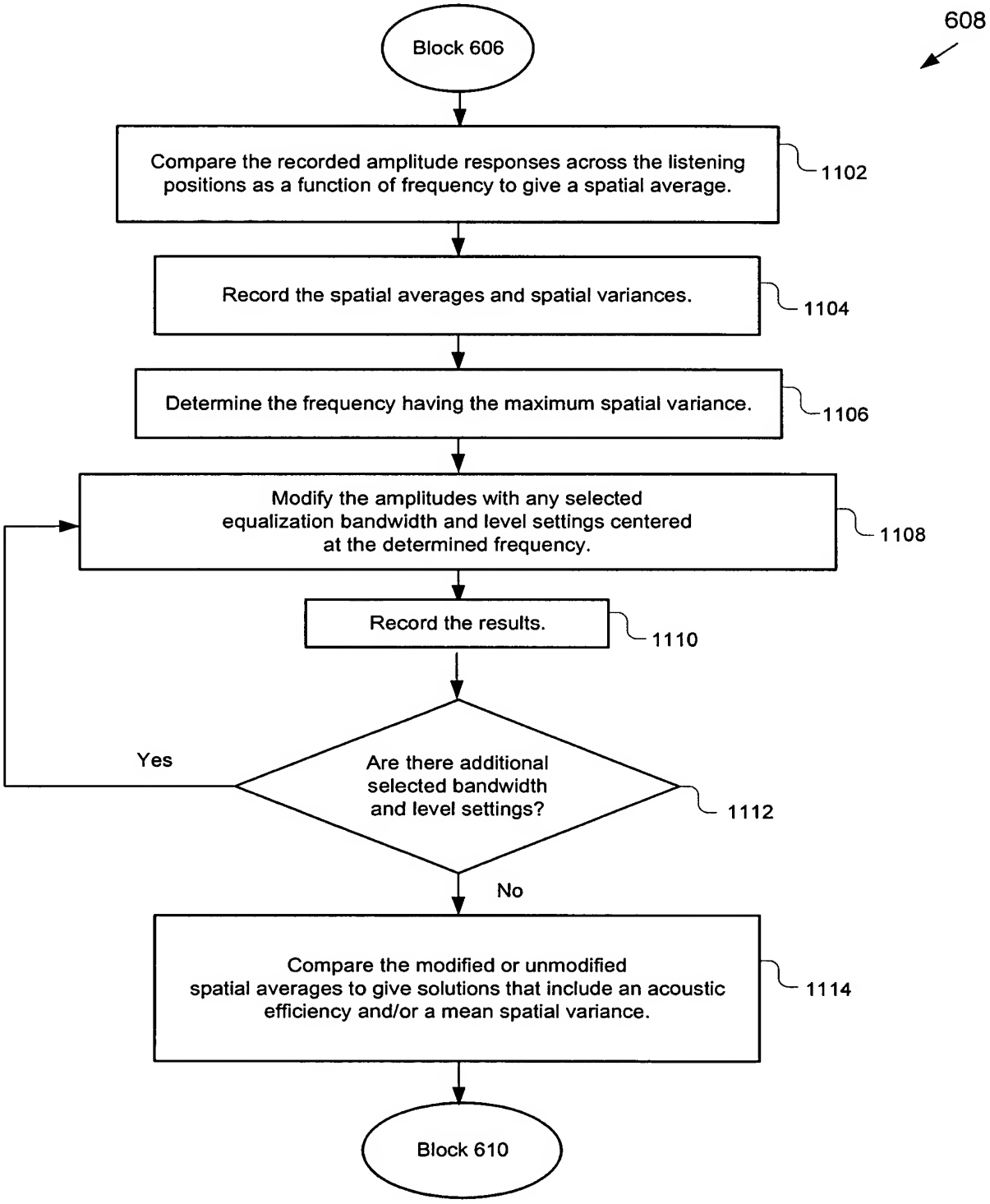

608
Block 606
Compare the recorded amplitude responses across the listening positions as a function of frequency to give a spatial average.
1102
Record the spatial averages and spatial variances.
1104
Determine the frequency having the maximum spatial variance.
1106
Modify the amplitudes with any selected equalization bandwidth and level settings centered at the determined frequency.
1108
Record the results.
1110
Are there additional selected bandwidth and level settings?
1112
Yes
No
Compare the modified or unmodified spatial averages to give solutions that include an acoustic efficiency and/or a mean spatial variance.
1114
Block 610

FIG. 12

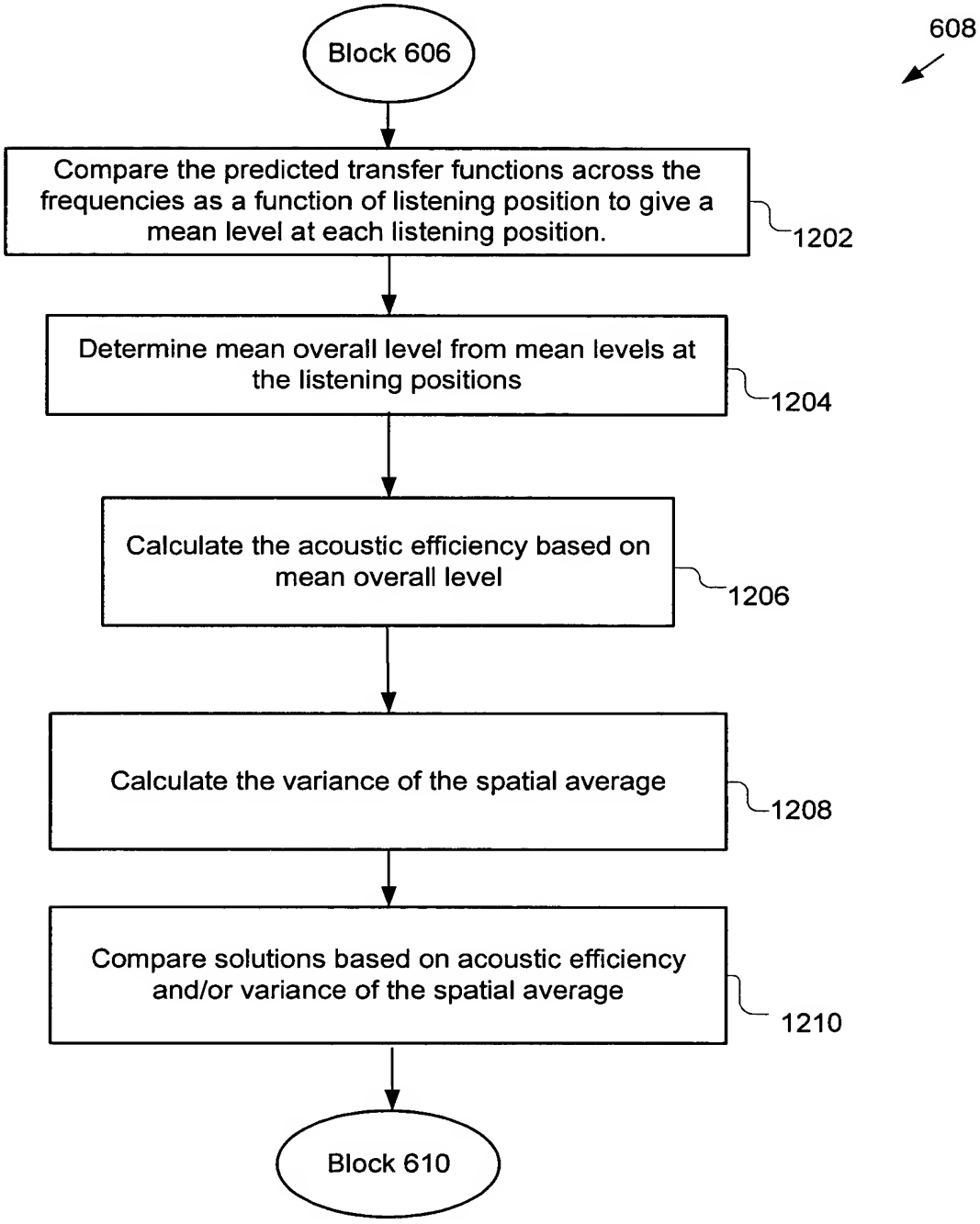
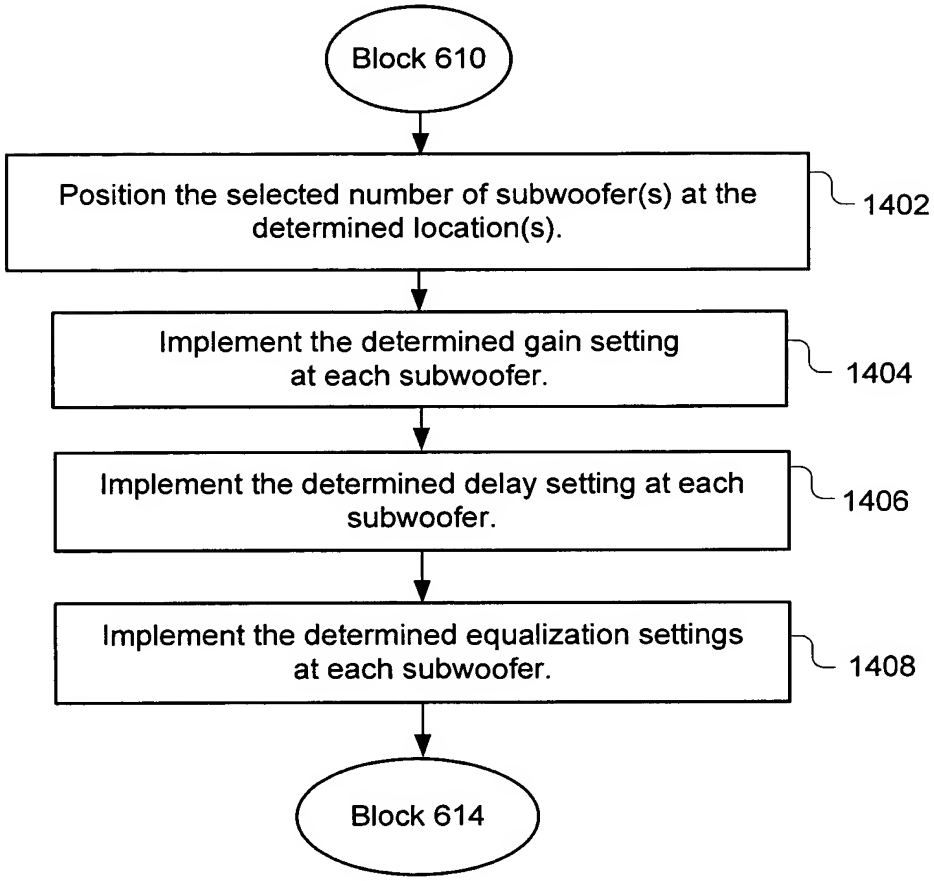

608
Block 606
Compare the predicted transfer functions across the frequencies as a function of listening position to give a mean level at each listening position.
1202
Determine mean overall level from mean levels at the listening positions
1204
Calculate the acoustic efficiency based on mean overall level
1206
Calculate the variance of the spatial average
1208
Compare solutions based on acoustic efficiency and/or variance of the spatial average
1210
Block 610

FIG. 13

Illustrative Solution Sets Ranked by Spatial Variance

Solution	MSV	AE	VSA	S	Gain (dB)	Delay (ms)	Eq. Center (Hz)	Eq Bandwidth (Q)	Eq. Level (dB)
1	4.0	12	18	1, 2	0, 0	0, 5	82, 37	1, 4	0, -6
2	4.4	19	15	1, 2, 3	-6, 0, -12	0, 10, 0	22, 64, 85	1, 4, 1	-12, 0, -6
3	5	14	13	2, 3	-6, 0	10, 0	27, 41	8, 1	-6, -12
4	6	10	16	3, 4	-12, 0	0, 0	93, 51	1, 8	-12, 0
5	10	23	20	1, 3, 4	0, -12, 0	5, 0	34, 86	1, 1, 8	0, 0, -12
10,000	17	2	56	1, 4	-6, -12	0, 10	27, 91	8, 8	-6, -12, -6

FIG. 14


Block 610
612
Position the selected number of subwoofer(s) at the determined location(s).
1402
Implement the determined gain setting at each subwoofer.
1404
Implement the determined delay setting at each subwoofer.
1406
Implement the determined equalization settings at each subwoofer.
1408
Block 614

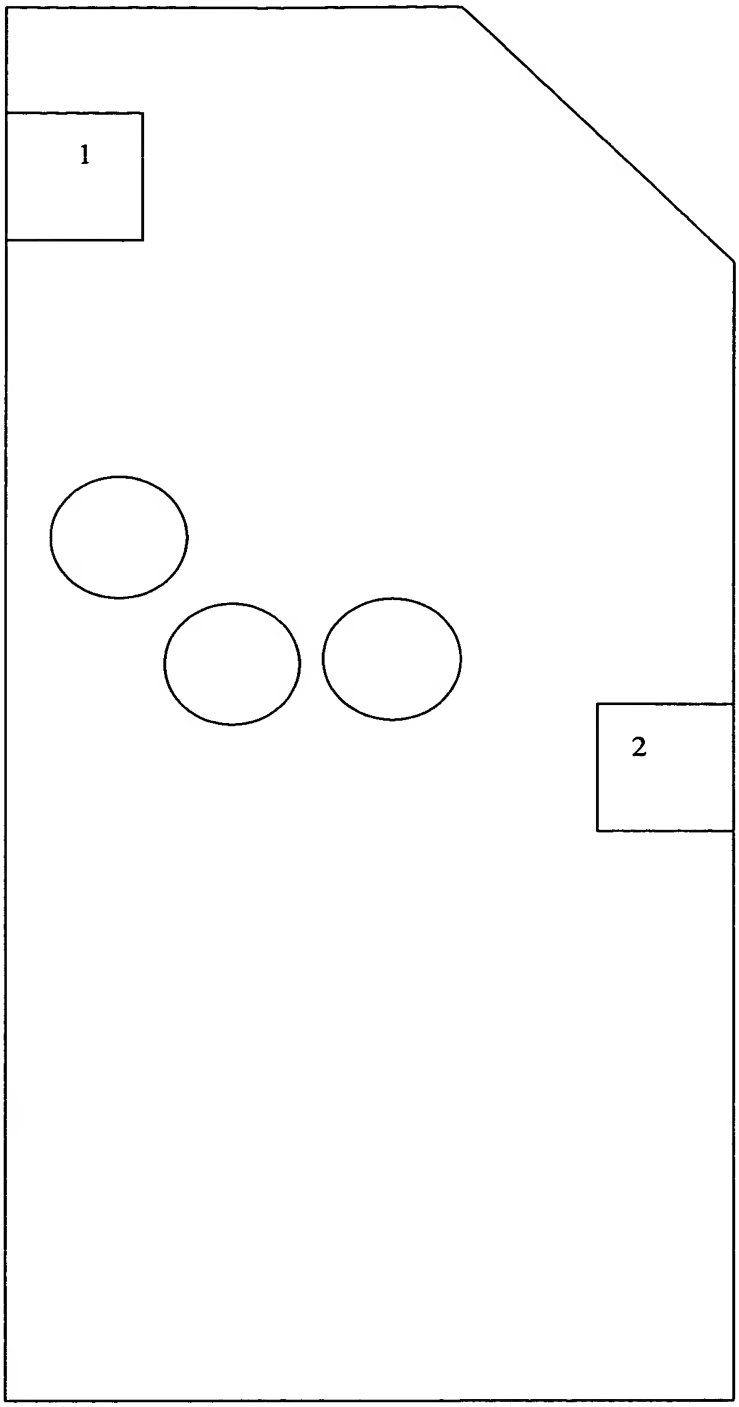


FIG. 15

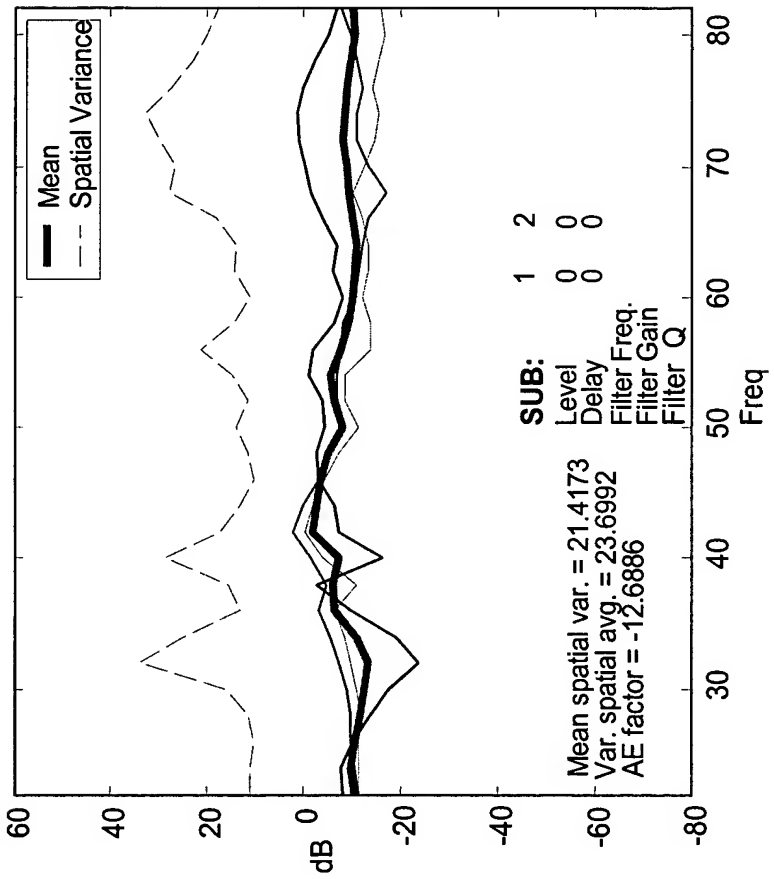

Mean
Spatial Variance
60
40
20
0
-20
-40
-60
-80
dB
30
40
50
60
70
80
Freq
SUB: 1 2
Level 0 0
Delay 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 21.4173
Var. spatial avg. = 23.6992
AE factor = -12.6886

FIG. 16

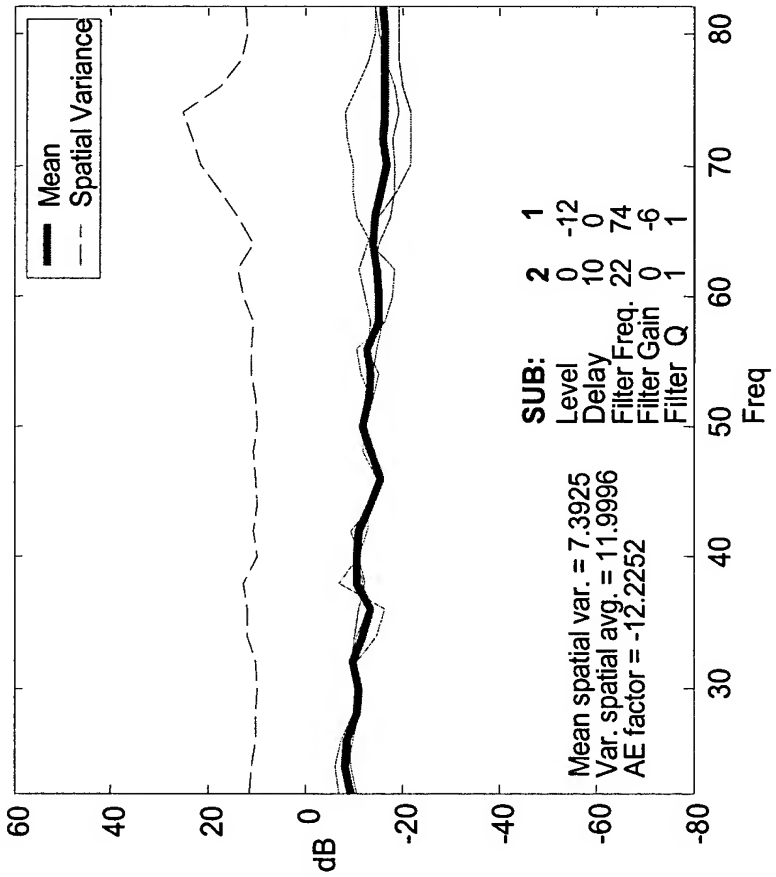

Mean
Spatial Variance
SUB: 2 1
Level 0 -12
Delay 10 0
Filter Freq. 22 74
Filter Gain 0 -6
Filter Q 1 1
Mean spatial var. = 7.3925
Var. spatial avg. = 11.9996
AE factor = -12.2252
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq

FIG. 17

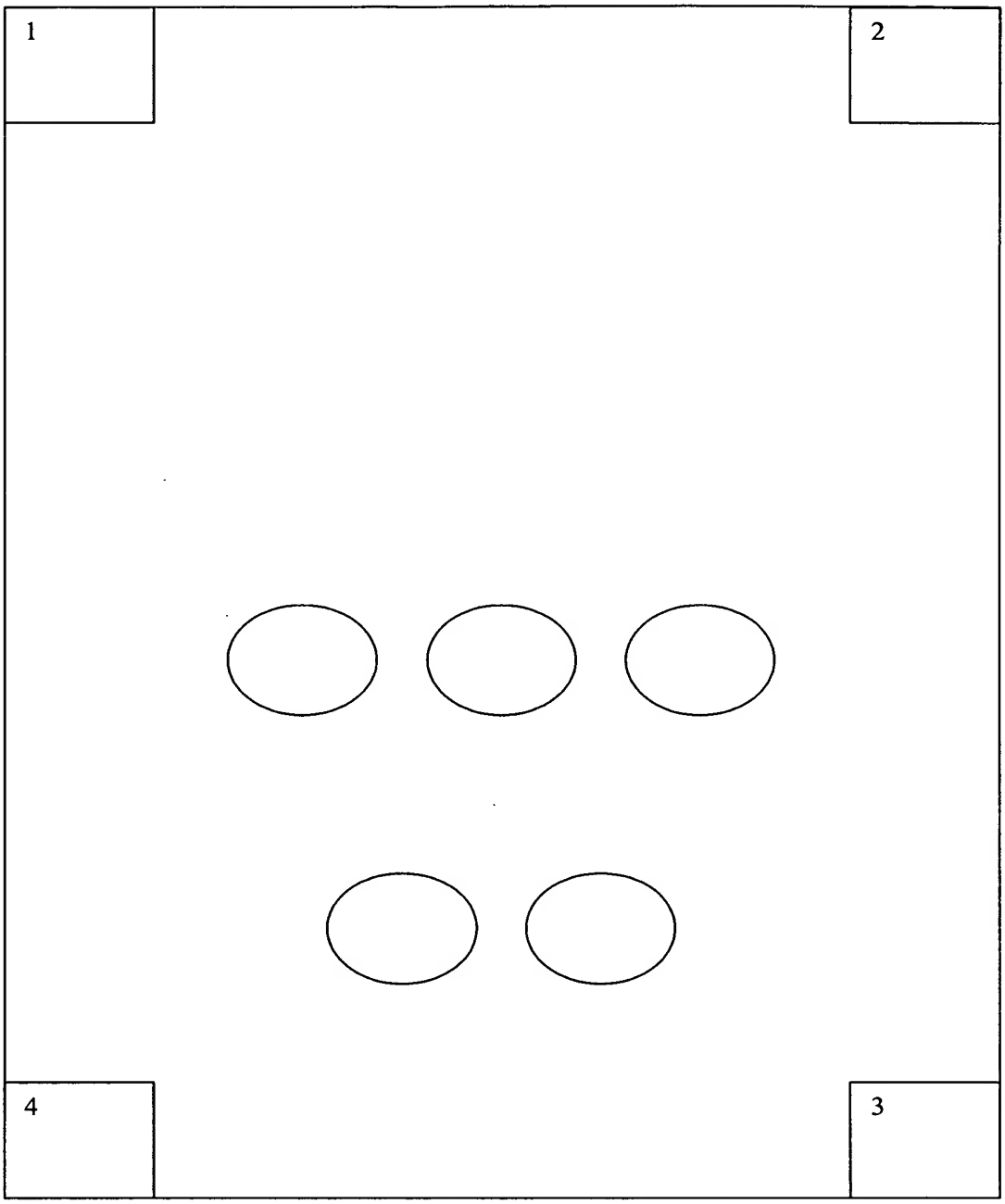


FIG. 18

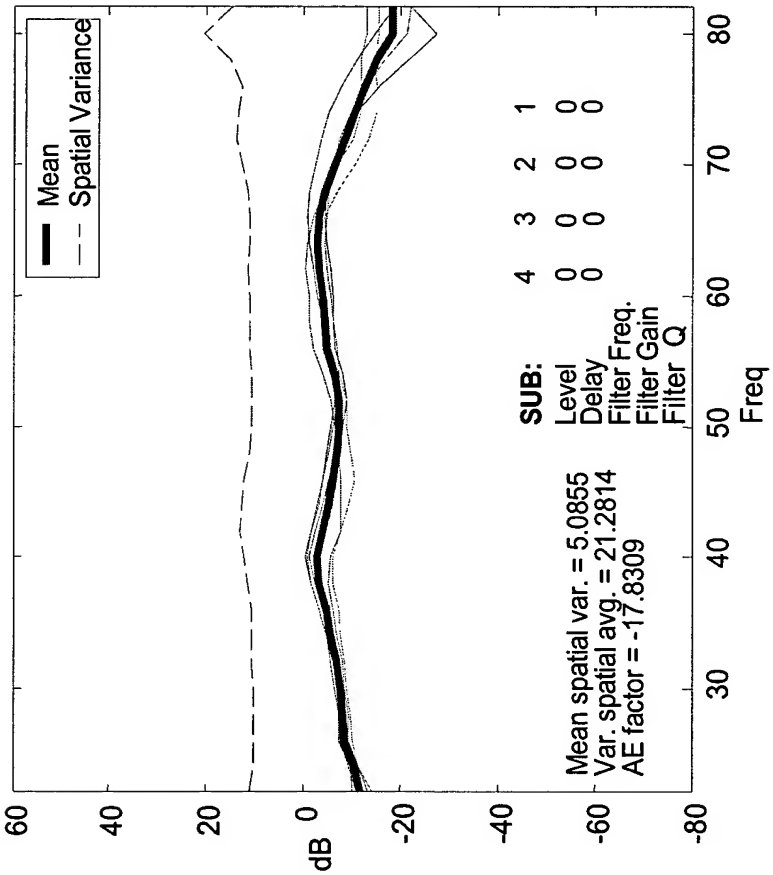

Mean
Spatial Variance
SUB: 4 3 2 1
Level 0 0 0 0
Delay 0 0 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 5.0855
Var. spatial avg. = 21.2814
AE factor = -17.8309
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq

FIG. 19

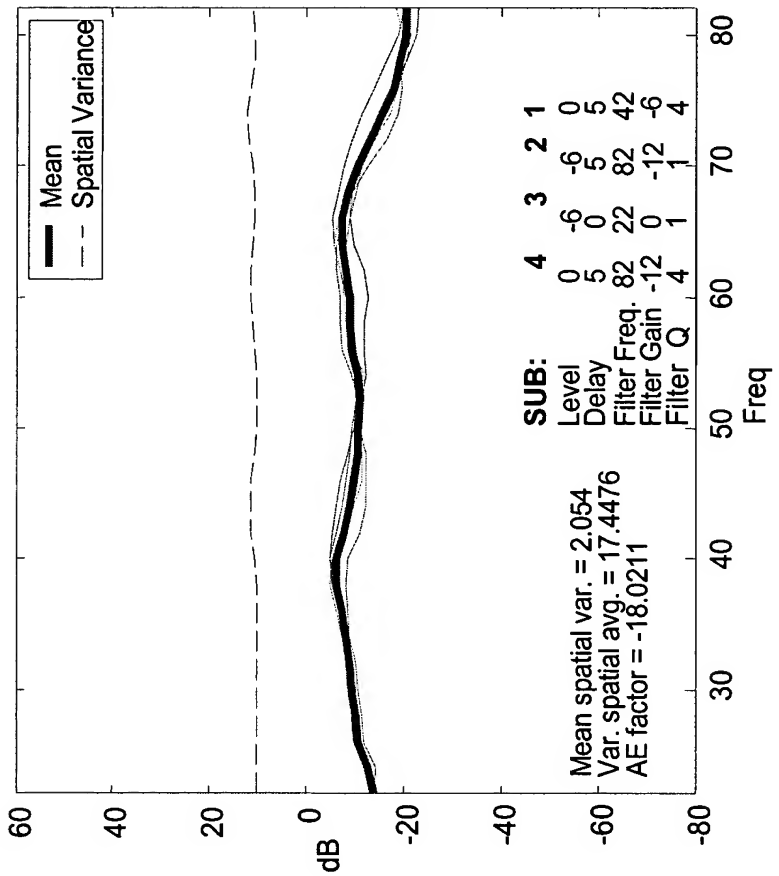

Mean
Spatial Variance
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq
SUB: 4 3 2 1
Level 0 -6 -6 0
Delay 5 0 5 5
Filter Freq. 82 22 82 42
Filter Gain -12 0 -12 -6
Filter Q 4 1 1 4
Mean spatial var. = 2.054
Var. spatial avg. = 17.4476
AE factor = -18.0211

FIG. 20

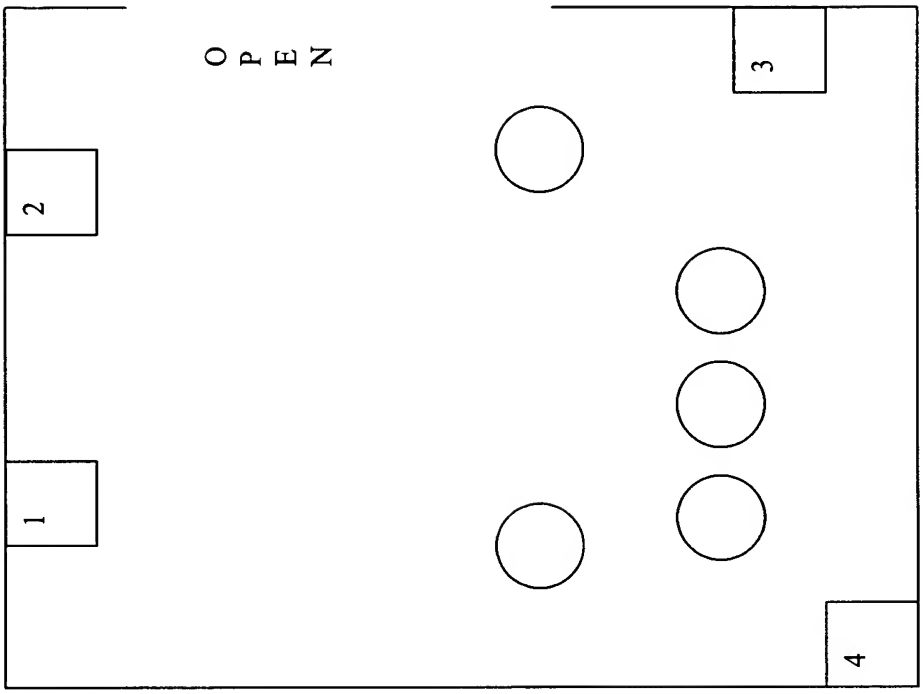


FIG. 21

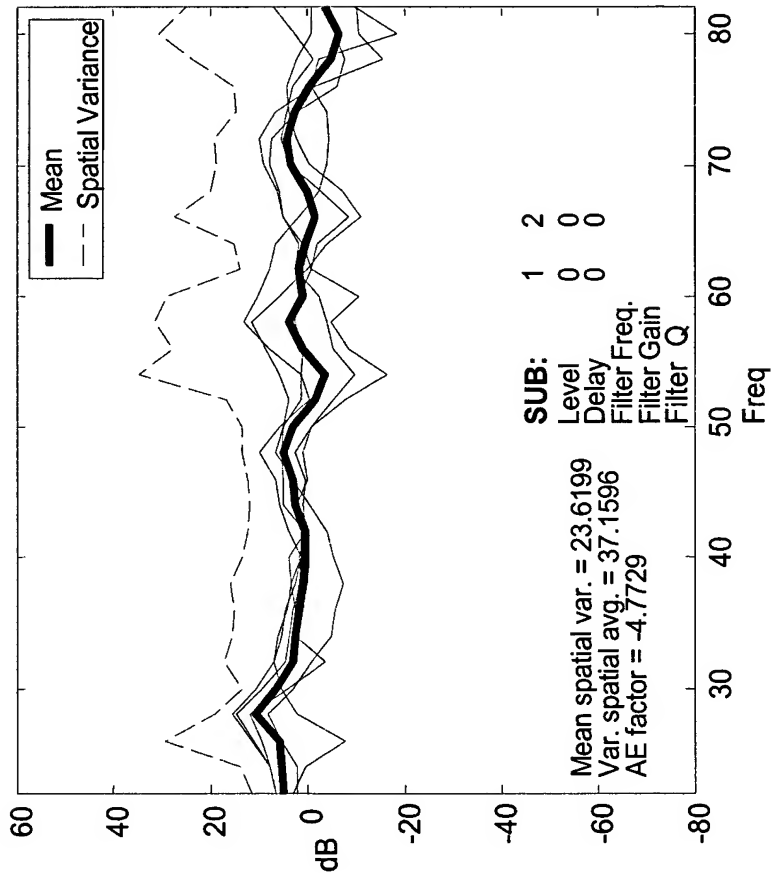

Mean
Spatial Variance
SUB: 1 2
Level 0 0
Delay 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 23.6199
Var. spatial avg. = 37.1596
AE factor = -4.7729
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80

FIG. 22

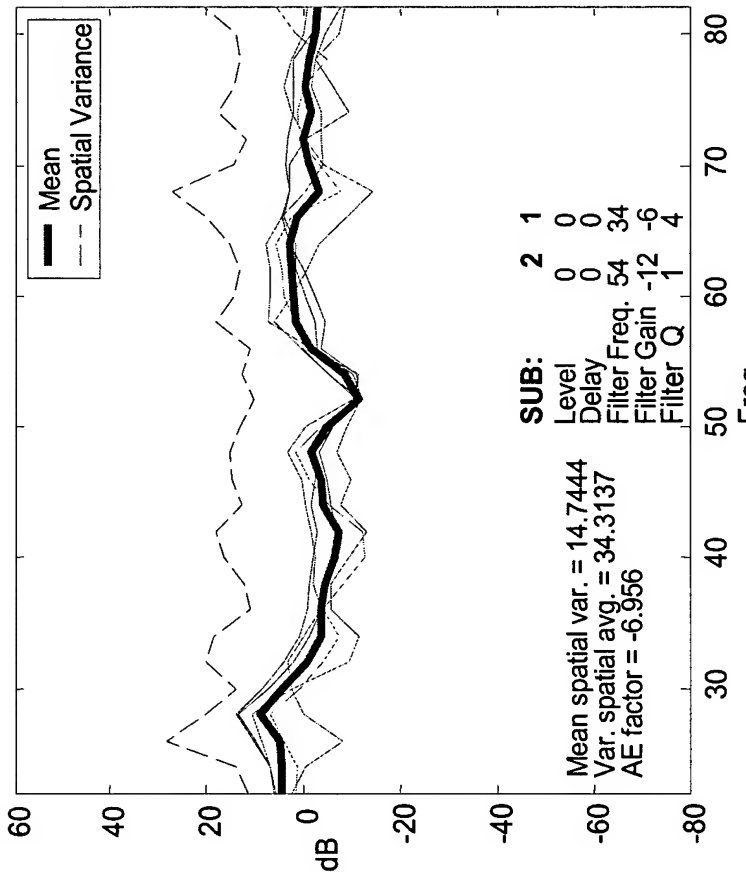

Mean
Spatial Variance
SUB: 2 1
Level 0 0
Delay 0 0
Filter Freq. 54 34
Filter Gain -12 -6
Filter Q 1 4
Mean spatial var. = 14.7444
Var. spatial avg. = 34.3137
AE factor = -6.956
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80

FIG. 23

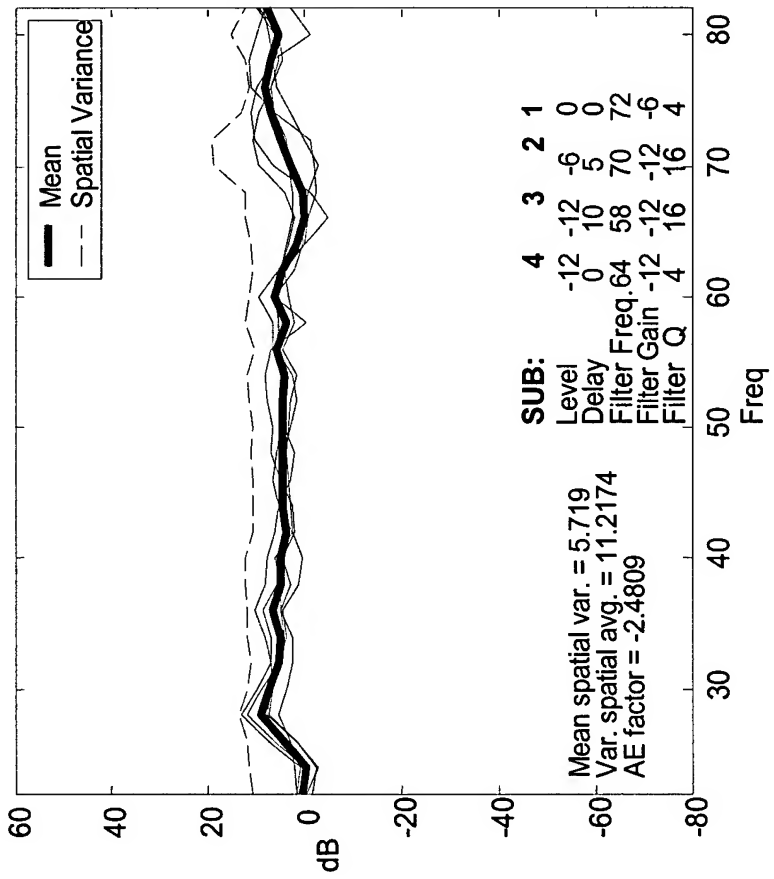

Mean
Spatial Variance
SUB: 4 3 2 1
Level -12 -12 -6 0
Delay 0 10 5 0
Filter Freq. 64 58 70 72
Filter Gain -12 -12 -12 -6
Filter Q 4 16 16 4
Mean spatial var. = 5.719
Var. spatial avg. = 11.2174
AE factor = -2.4809
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80

FIG. 24

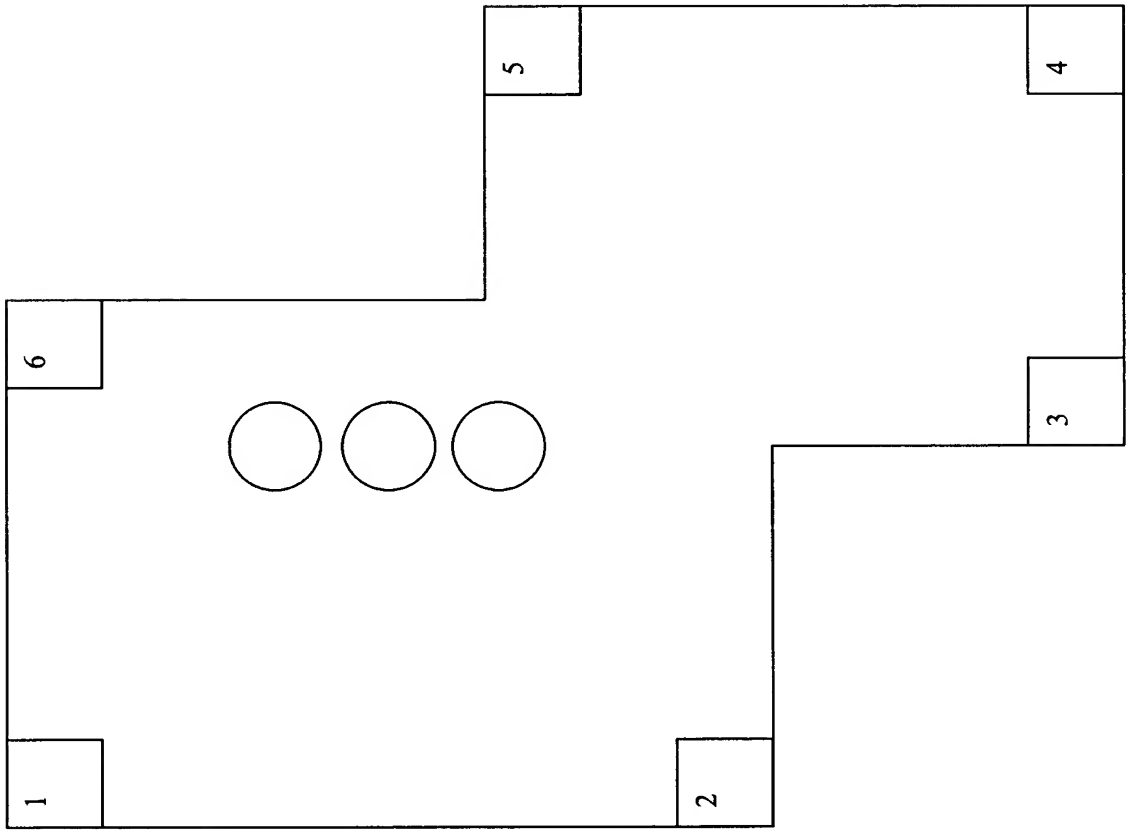


FIG. 25

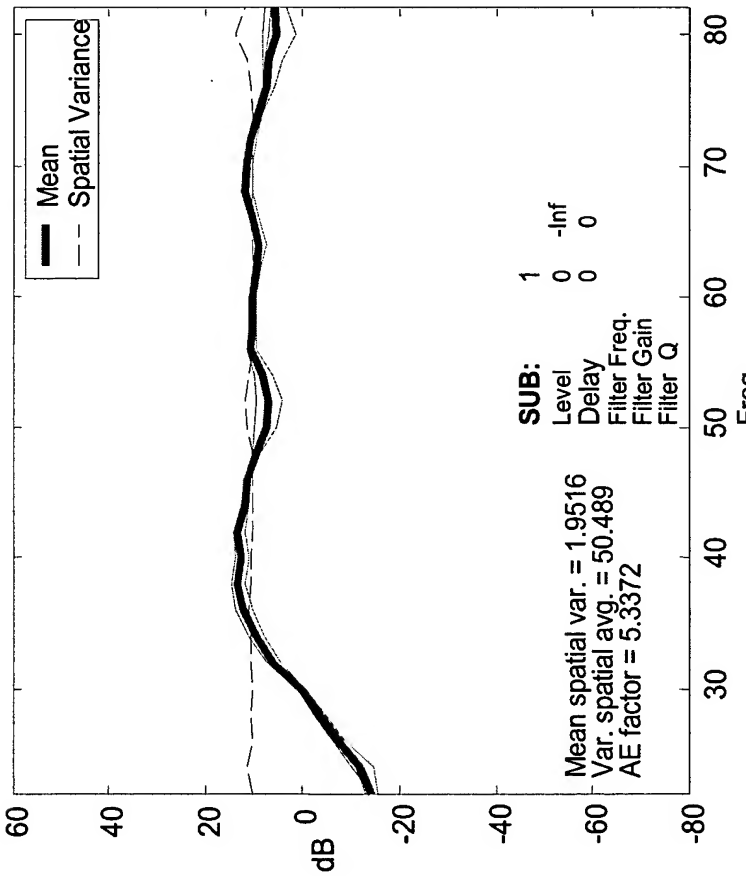

Mean
Spatial Variance
SUB: 1
Level 0 -Inf
Delay 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 1.9516
Var. spatial avg. = 50.489
AE factor = 5.3372
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq

FIG. 26

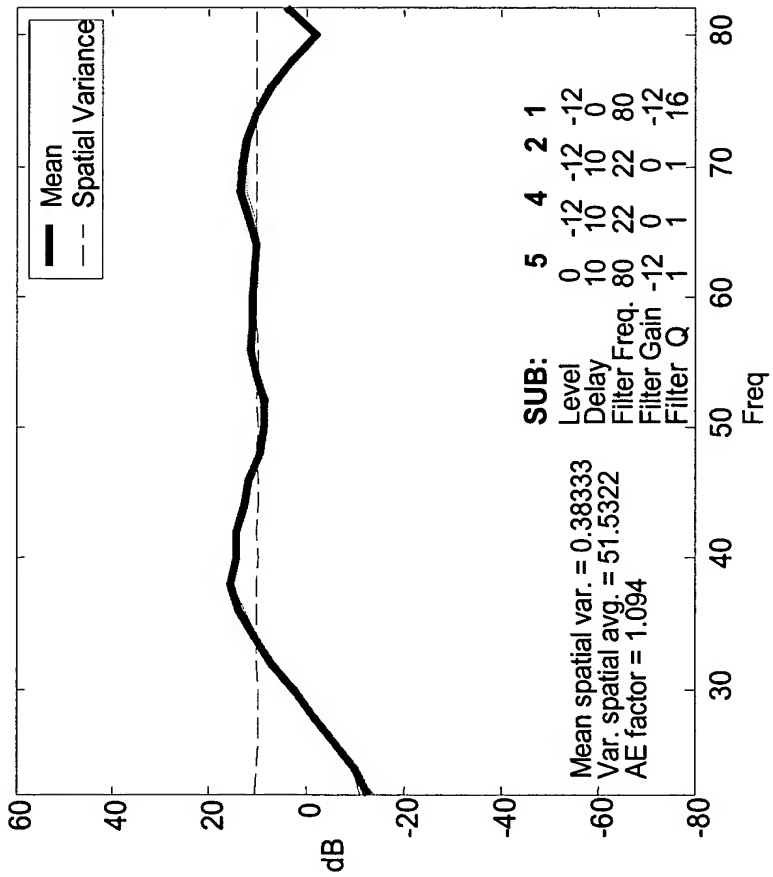

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 5 4 2 1
Level 0 -12 -12 -12
Delay 10 10 10 0
Filter Freq. 80 22 22 80
Filter Gain -12 0 0 -12
Filter Q 1 1 1 16
Mean spatial var. = 0.38333
Var. spatial avg. = 51.5322
AE factor = 1.094

FIG. 27

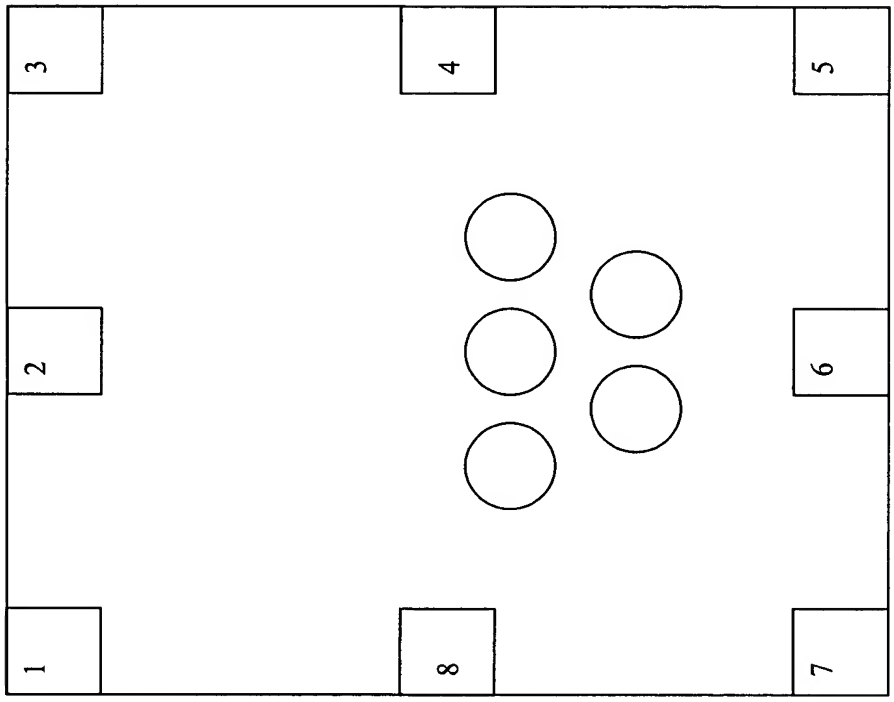


FIG. 28

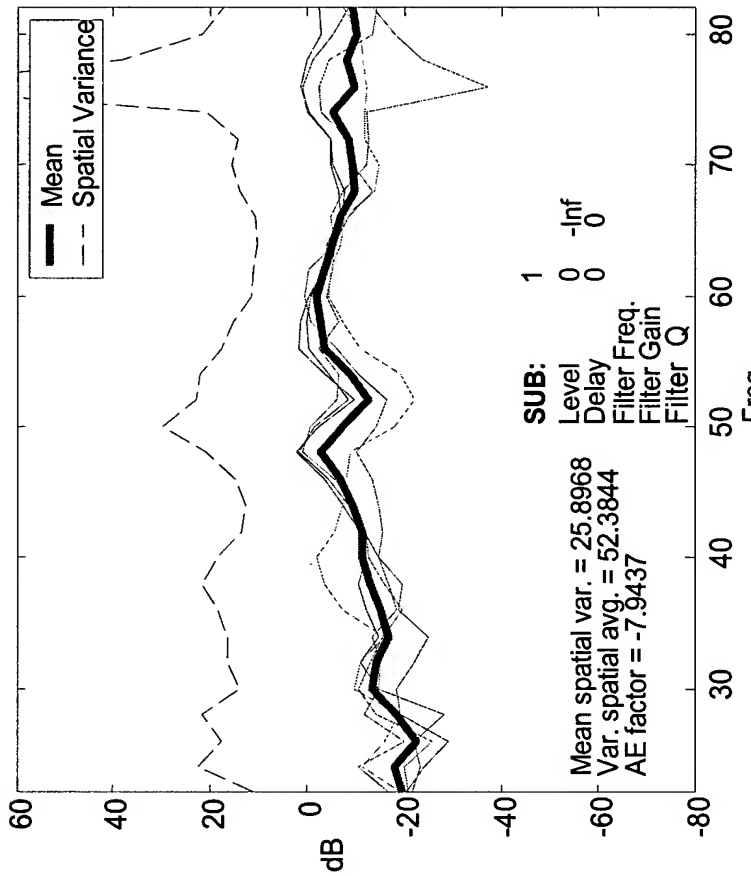

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 1
Level 0
Delay 0
Filter Freq. -Inf
Filter Gain 0
Filter Q
Mean spatial var. = 25.8968
Var. spatial avg. = 52.3844
AE factor = -7.9437

FIG. 29

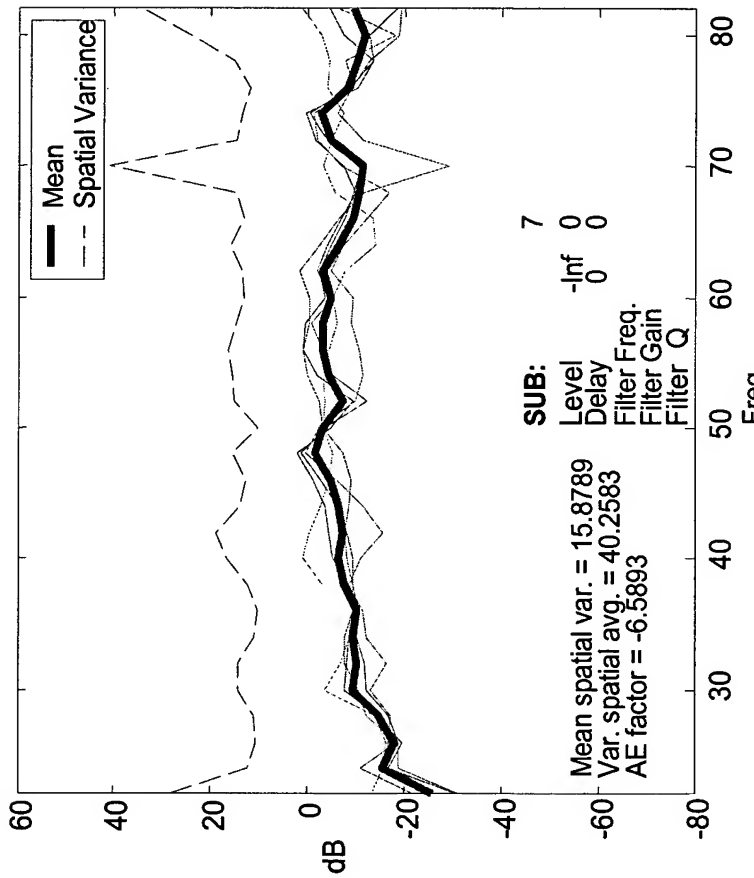

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 7
Level -Inf 0
Delay 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 15.8789
Var. spatial avg. = 40.2583
AE factor = -6.5893

FIG. 30

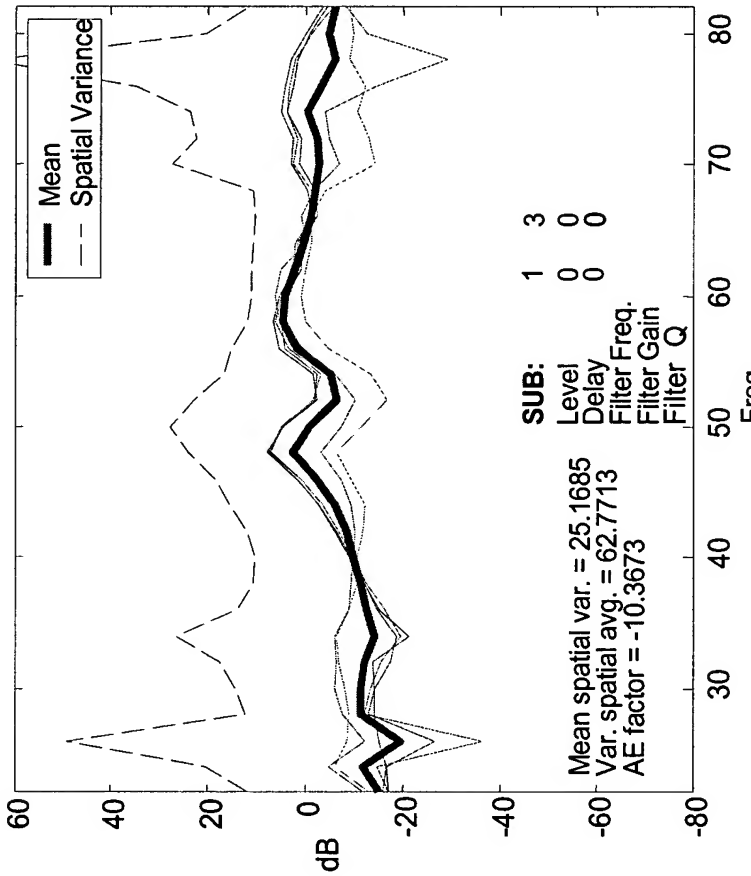

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 1 3
Level 0 0
Delay 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 25.1685
Var. spatial avg. = 62.7713
AE factor = -10.3673

FIG. 31

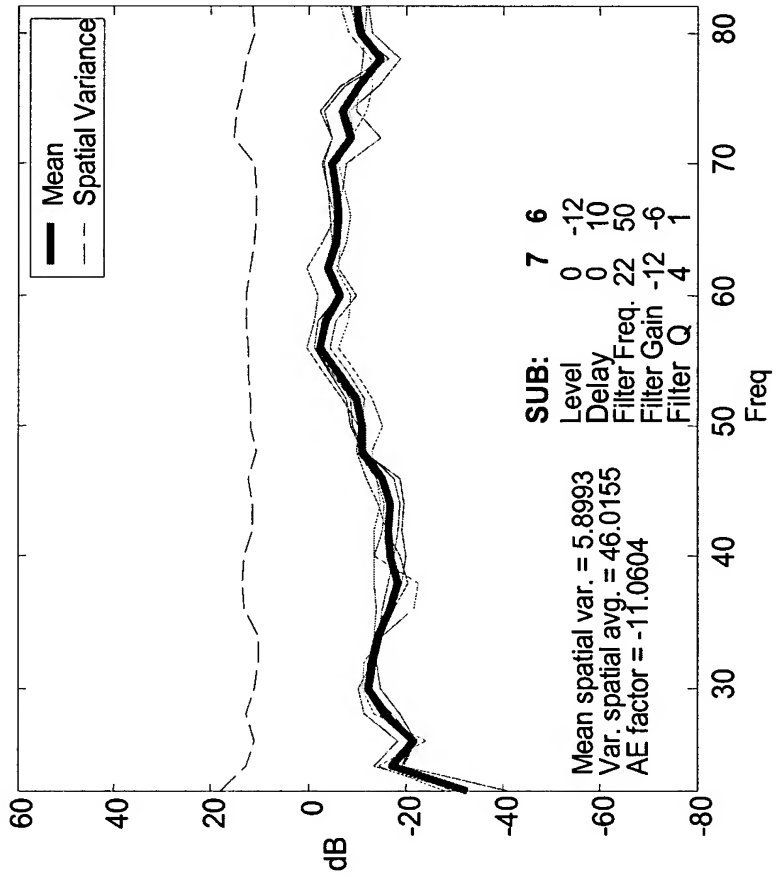

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 7 6
Level 0 -12
Delay 0 10
Filter Freq. 22 50
Filter Gain -12 -6
Filter Q 4 1
Mean spatial var. = 5.8993
Var. spatial avg. = 46.0155
AE factor = -11.0604

FIG. 32

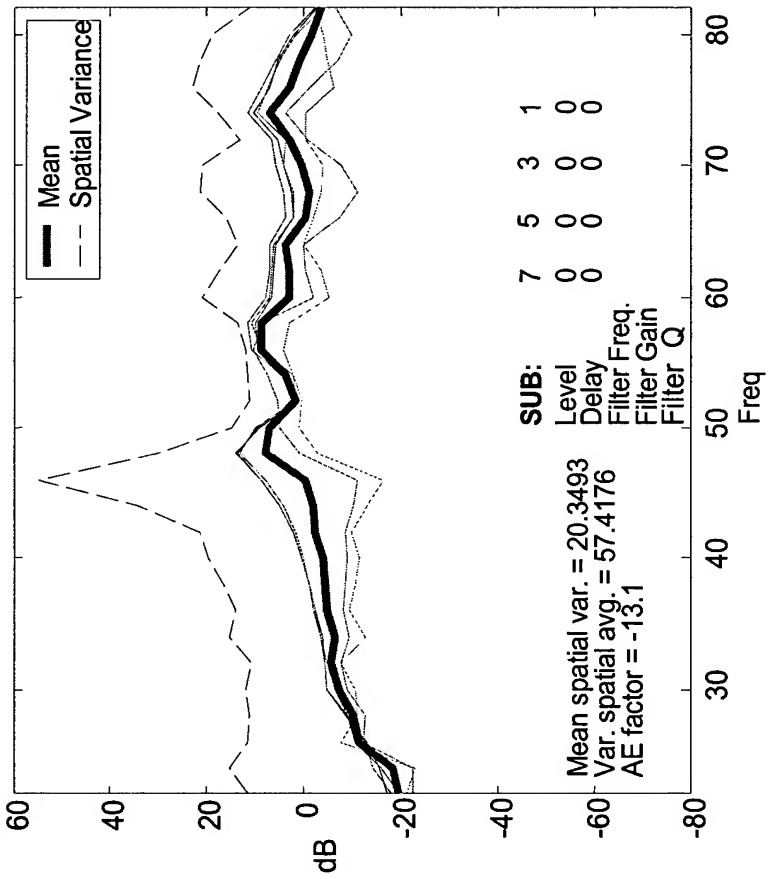

Mean
Spatial Variance
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq
SUB: 7 5 3 1
Level 0 0 0 0
Delay 0 0 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 20.3493
Var. spatial avg. = 57.4176
AE factor = -13.1

FIG. 33

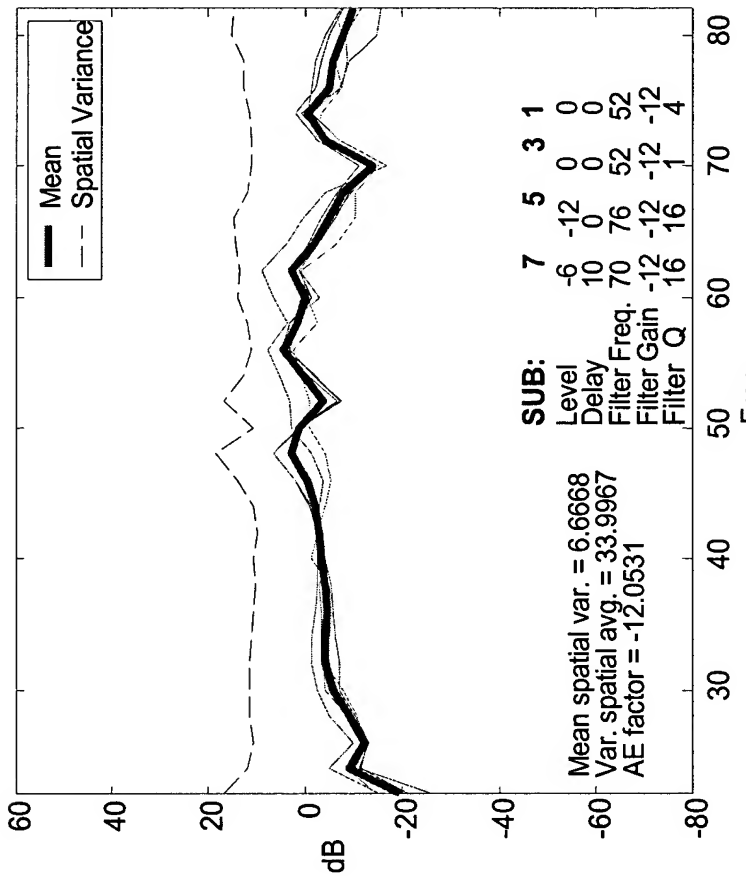

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 7 5 3 1
Level -6 -12 0 0
Delay 10 0 0 0
Filter Freq. 70 76 52 52
Filter Gain -12 -12 -12 -12
Filter Q 16 16 1 4
Mean spatial var. = 6.6668
Var. spatial avg. = 33.9967
AE factor = -12.0531

FIG. 34

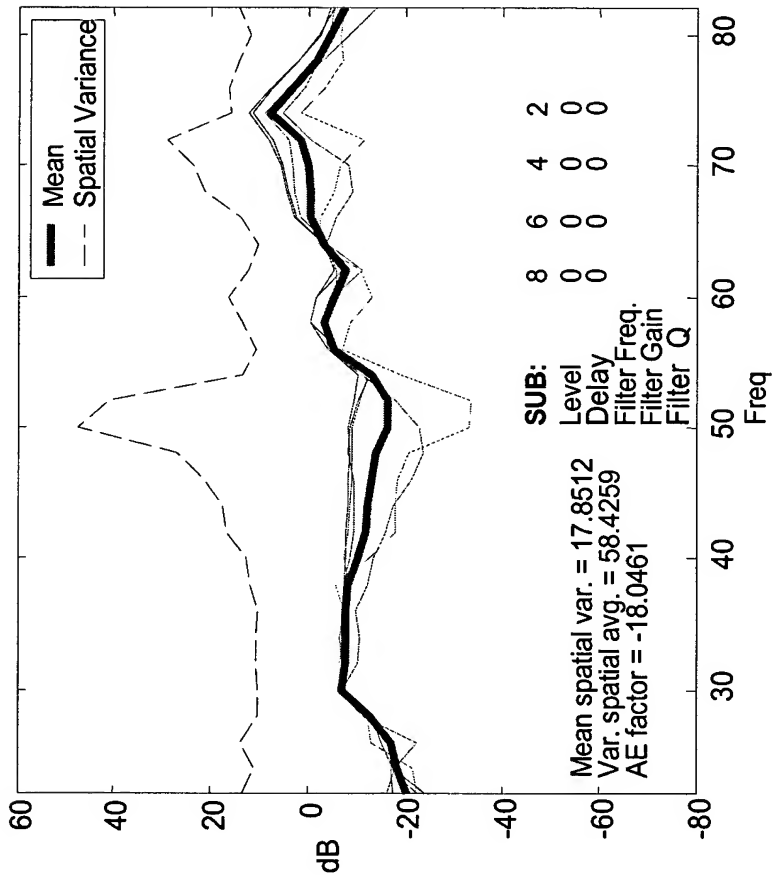

Mean
Spatial Variance
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq
SUB: 8 6 4 2
Level 0 0 0 0
Delay 0 0 0 0
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 17.8512
Var. spatial avg. = 58.4259
AE factor = -18.0461

FIG. 35

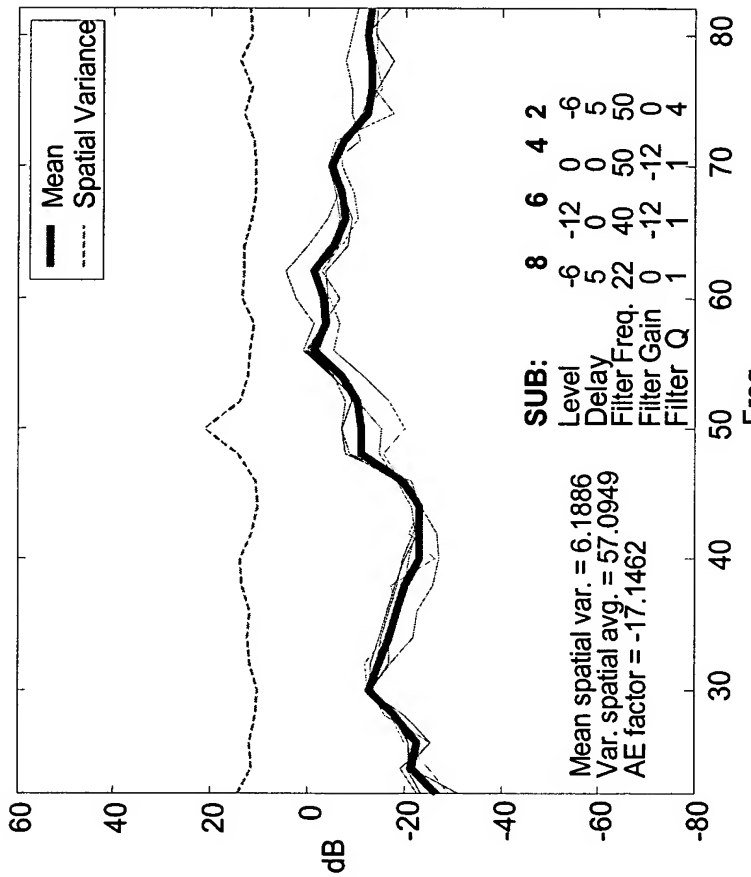

Mean
Spatial Variance
dB
Freq
SUB: 8 6 4 2
Level -6 -12 0 -6
Delay 5 0 0 5
Filter Freq. 22 40 50 50
Filter Gain 0 -12 -12 0
Filter Q 1 1 1 4
Mean spatial var. = 6.1886
Var. spatial avg. = 57.0949
AE factor = -17.1462

FIG. 36

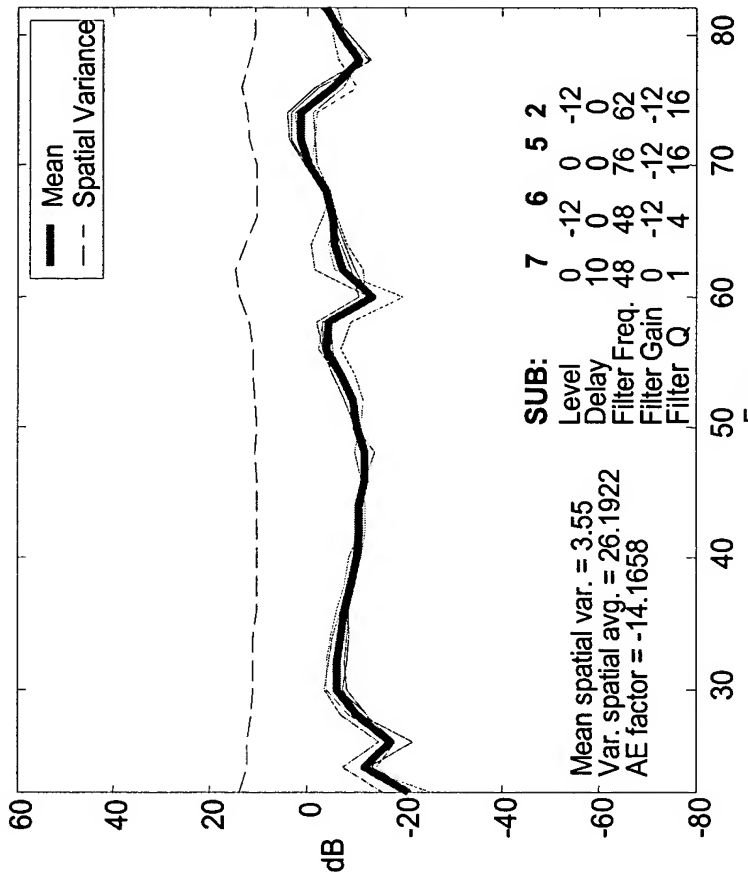

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 7 6 5 2
Level 0 -12 0 -12
Delay 10 0 0 0
Filter Freq. 48 48 76 62
Filter Gain 0 -12 -12 -12
Filter Q 1 4 16 16
Mean spatial var. = 3.55
Var. spatial avg. = 26.1922
AE factor = -14.1658

FIG. 37

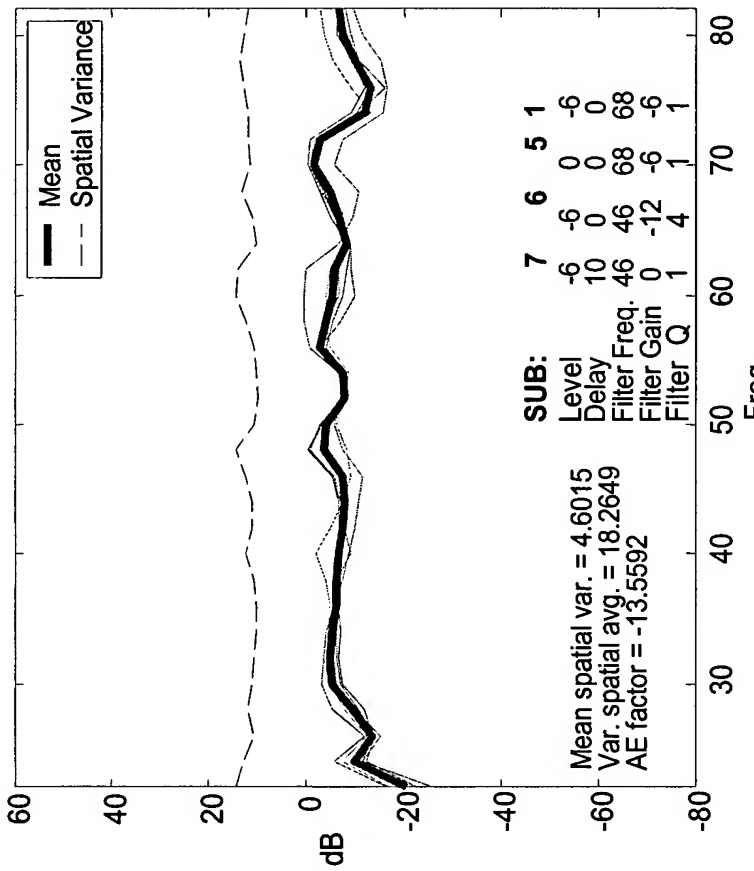

Mean
Spatial Variance
dB
Freq
SUB: 7 6 5 1
Level -6 -6 0 -6
Delay 10 0 0 0
Filter Freq. 46 46 68 68
Filter Gain 0 -12 -6 -6
Filter Q 1 4 1 1
Mean spatial var. = 4.6015
Var. spatial avg. = 18.2649
AE factor = -13.5592

FIG. 38

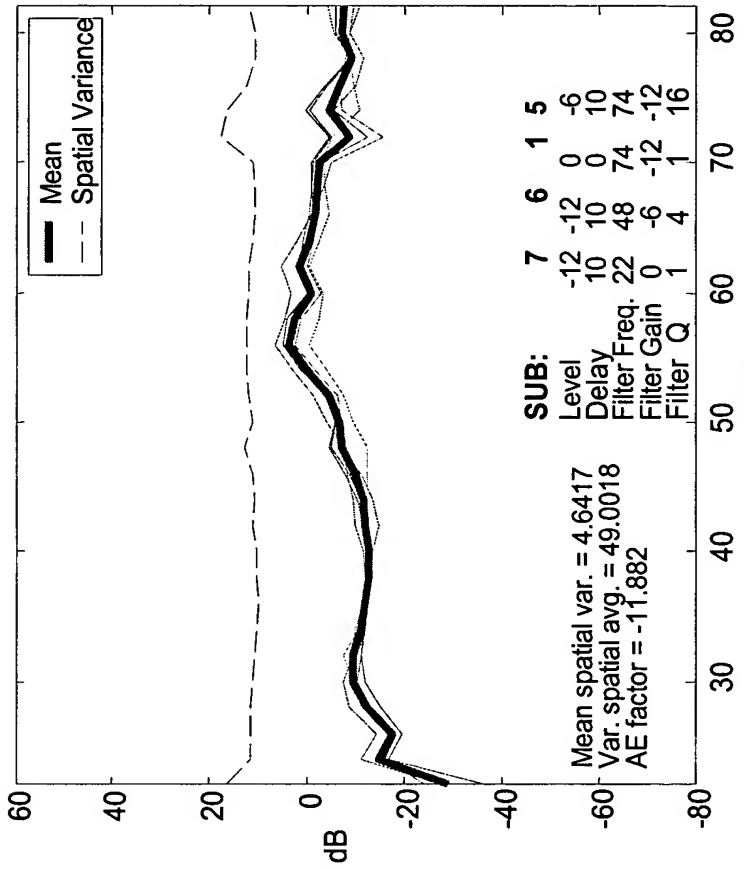

Mean
Spatial Variance
dB
Freq
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
SUB: 7 6 1 5
Level -12 -12 0 -6
Delay 10 10 0 10
Filter Freq. 22 48 74 74
Filter Gain 0 -6 -12 -12
Filter Q 1 4 1 16
Mean spatial var. = 4.6417
Var. spatial avg. = 49.0018
AE factor = -11.882

FIG. 39

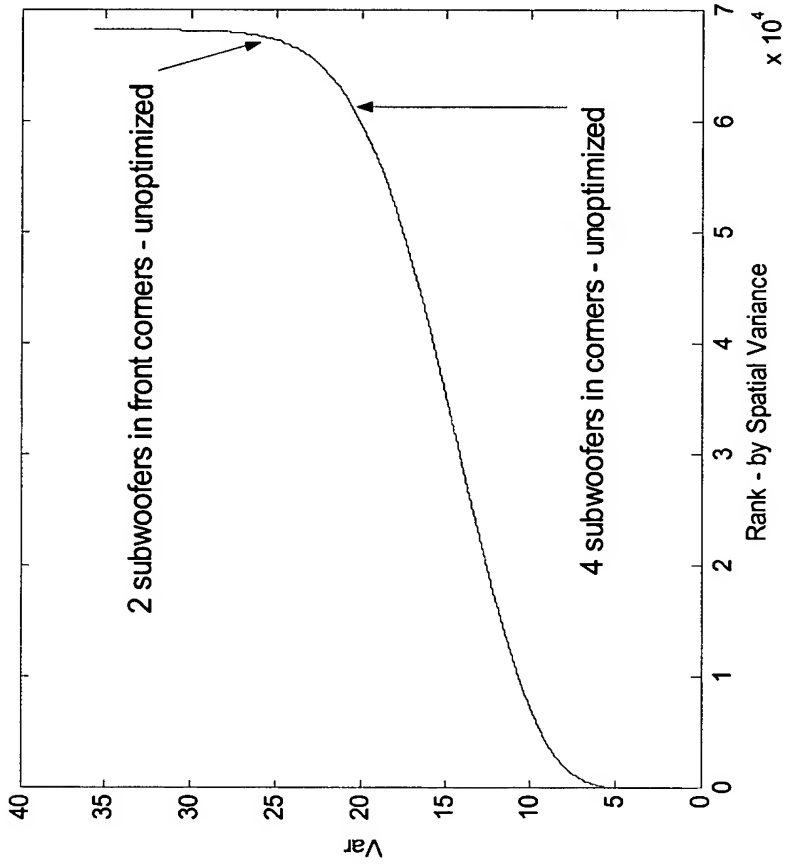

2 subwoofers in front corners - unoptimized
4 subwoofers in corners - unoptimized
Var
Rank - by Spatial Variance
x 10^4
0
5
10
15
20
25
30
35
40
1
2
3
4
5
6
7

FIG. 40

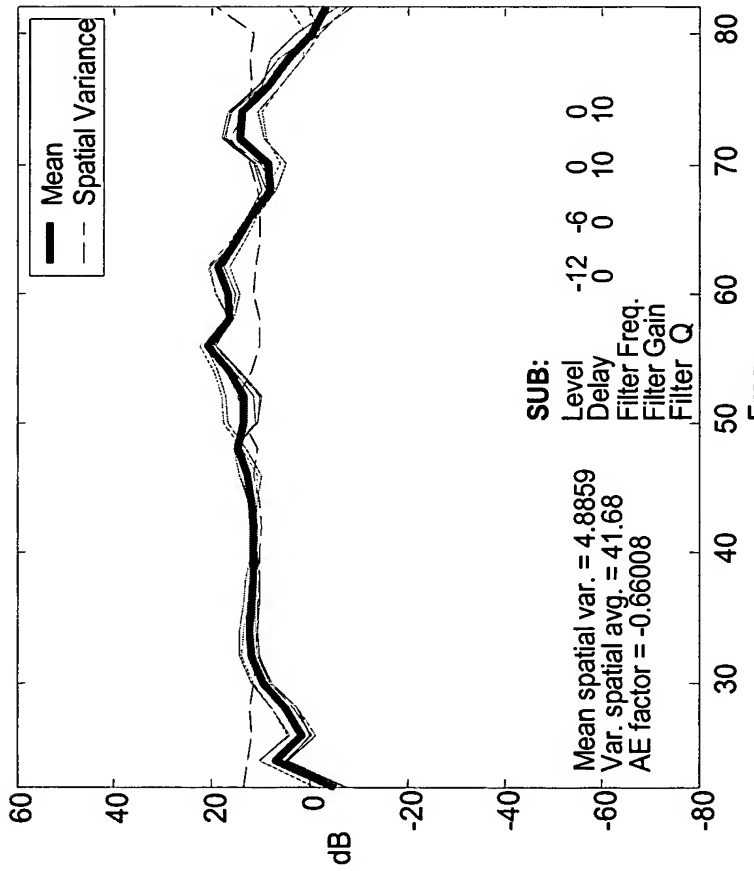

Mean
Spatial Variance
SUB:
Level -12 -6 0 0
Delay 0 0 10 10
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 4.8859
Var. spatial avg. = 41.68
AE factor = -0.66008
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq

FIG. 41

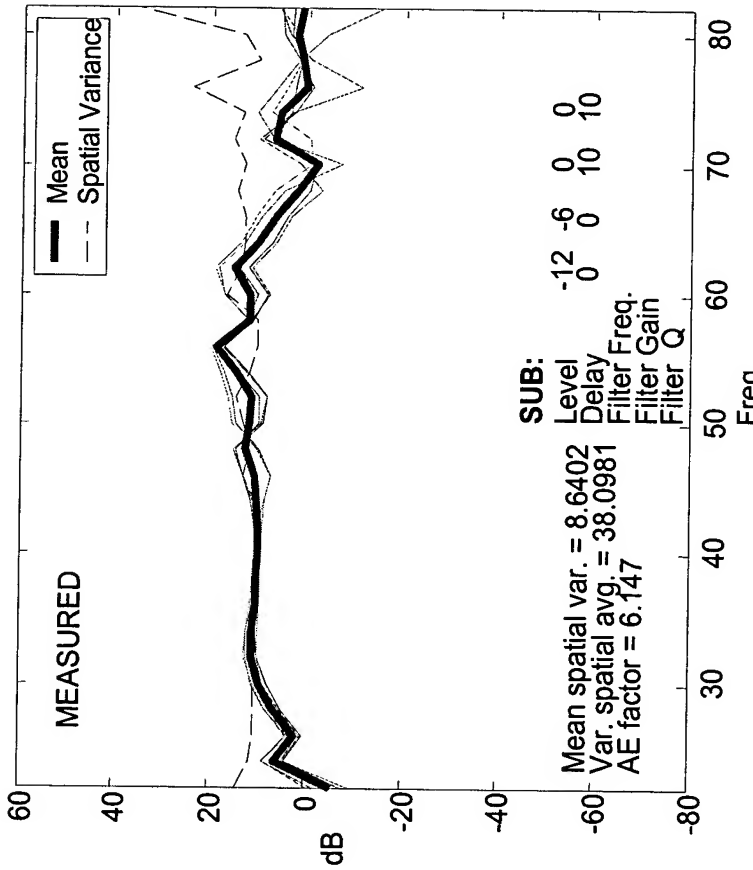

Mean
Spatial Variance
MEASURED
SUB:
Level -12 -6 0 0
Delay 0 0 10 10
Filter Freq.
Filter Gain
Filter Q
Mean spatial var. = 8.6402
Var. spatial avg. = 38.0981
AE factor = 6.147
dB
60
40
20
0
-20
-40
-60
-80
30
40
50
60
70
80
Freq

FIG. 42